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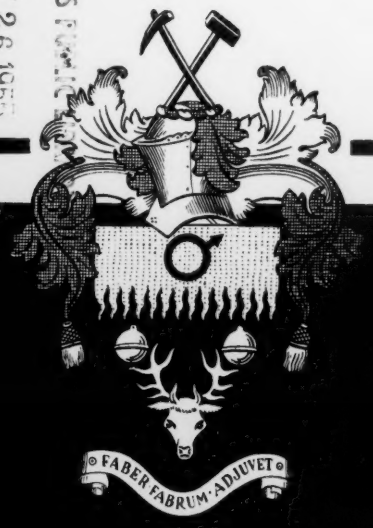

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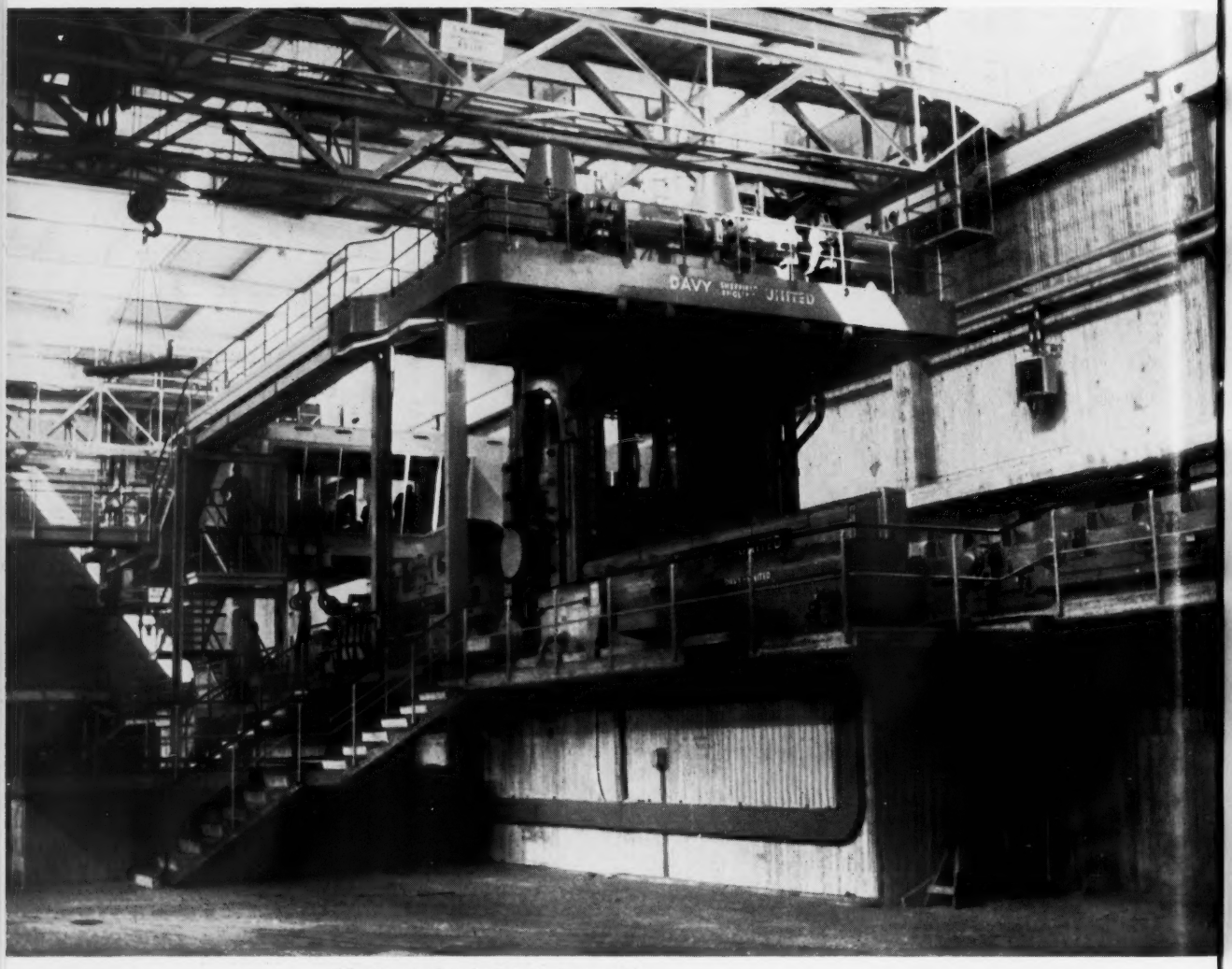
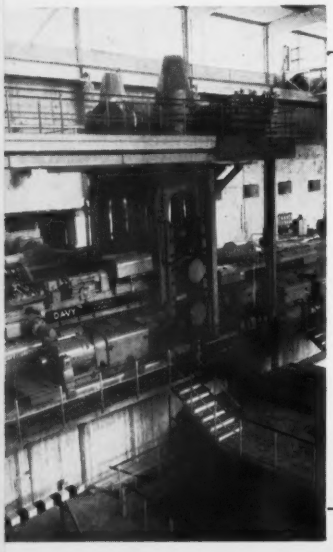
New Blooming and Slabbing Mill Plant

at SANDVIKEN



View from the Outgoing Side showing one of the distinctive features, the elevated level of the rolling line with the oil-cellars housed in the concrete foundations above ground level.



Electric universal manipulators, with 4-finger tilting gear and special bobbin type tilters are fitted in the ingoing side.

Recently put into commission by Sandvikens Jernverks A.B. is a Davy-United 42″ x 98½″ High Lift Blooming and Slabbing Mill, designed to handle high carbon and stainless steel ingots up to 4½ tons in weight and to roll a variety of products ranging from 5″ rounds up to slabs measuring 52″x5″. The mill is equipped with all necessary roller tables, electric universal manipulators of the side guard type, has S.K.F. roller bearings on the roll necks and is driven by a 5,840 h.p. motor. It is the seventh major blooming and slabbing mill plant completed by Davy-United in the last ten years.

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ABBREVIATIONS AND SYMBOLS

A.	ampere(s)
A.hr.	ampère-hour(s)
Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled; alternating current
A.H.	air-hardened
approx.	approximately
A.S.T.M.	Grain size (American Society for Testing Materials number)
at.-%	atomic per cent.
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade; Celsius (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dil.	dilute
dm.	decimetre(s)
D.P.N.	Vickers diamond pyramid hardness number
e.m.f.	electromotive force
eV.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kcal.	kilogramme-calorie(s)
kg.	kilogramme(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units
l.	litre(s)
lb.	pound(s)
L.F.	low-frequency
M.	molar (solution)
m.	metre(s)
mA.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
$m\mu$	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent.
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg.	microgramme(s) = 1×10^{-6} g.
$\mu\mu$	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc; foot (feet)
″	second of arc; (inches)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\simeq$	approximately equal to
$\propto$	proportional to

SIR CHARLES BRUCE-GARDNER, Bt., M.I.Mech.E.

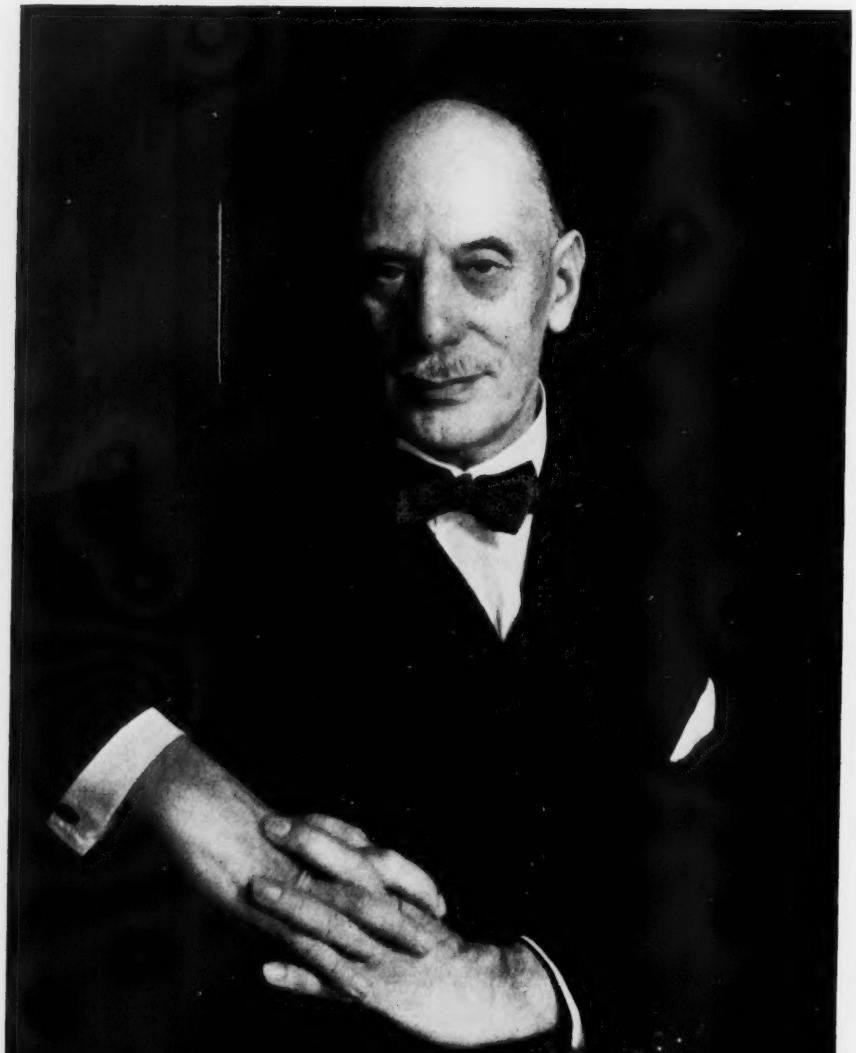
SIR CHARLES BRUCE-GARDNER, Bt., Chairman of John Lysaght Limited, was born in London and educated at St. Dunstan's College and at Battersea Technical College, afterwards serving his mechanical engineering apprenticeship at the Westinghouse Company's works at Trafford Park, Manchester. On completion of his apprenticeship, Sir Charles obtained an appointment with John Summers and Sons, Shotton, as Assistant to the Steelworks Manager and Rolling Mill Manager, afterwards succeeding to the position. Later he became Assistant Works Manager and then Works Manager, and was elected to the Board in 1913.

From 1929 to 1930 Sir Charles was Chairman of the Iron and Steel Industrial Research Council. At the same time, he became a Member of the Advisory Committee of the Department of Overseas Trade. In 1930 his activities were broadened to cover a much wider front of industry and commerce. In that year he joined the Bank of England to become Industrial Advisor to the Governors, and was also appointed Managing Director of the Bankers' Industrial Development Company, Limited, and of The Securities Management Trust, Limited, the Bank of England Company. Both companies, working in collaboration, were instrumental in providing finance for some of the steel industry's larger developments. In 1936, and in 1937, he was Chairman of the Iron and Steel Exchange.

In December, 1937, at the request of the Government, Sir Charles left the Bank of England to assist in the Government's air re-armament programme, and was appointed Independent Chairman of the Society of British Aircraft Constructors. During the Second World War he served on many Government Committees and in a number of executive positions.

Towards the end of the war Sir Charles was appointed by the President of the Board of Trade to the position of Chief Executive for Industrial Reconversion, to deal with the industrial problems arising from the change-over from war to peacetime conditions. At the completion of this work he returned to the steel industry and is now a Director of a number of steel companies.

Sir Charles is a Member of Council and of the Executive Committee of the British Iron and Steel Federation. He joined The Iron and Steel Institute in 1910 and was elected a Member of Council in 1950. He took office as President at the Annual General Meeting of the Institute on 27th April, 1955.



Sir Charles Bruce-Gardner, Bt., M.I.Mech.E.
President, 1955–56

PRESIDENTIAL ADDRESS

The Iron and Steel Institute

Our Industry— Decline and Recovery 1910–1933

By Sir Charles Bruce-Gardner, Bt., M.I.Mech.E.

The purpose of my address is to review the course of events that took place in the steel industry during the years 1910–1933. I have chosen this period because so many important events and changes took place which had lasting effects on the industry.

Statistics do not tell one everything and so I thought it might be of interest to you —and particularly to those members of the Institute who were not then actively engaged in the industry as I was—if I tried to pass on to you my impressions of those years. In doing so it will be necessary to refer to the reaction of the industry from time to time in its corporate capacity to the almost unprecedented problems it was called upon to solve. It is well to remember that the modern iron and steel industry was born in this country and all the essential processes were technically developed by and in our industry, which enjoyed almost a world monopoly during the last century.

BY 1910, THE INDUSTRY consisted of a number of strongly individualistic units, each endeavouring to improve its technology and economic competitive power. There were some associations dealing with the sales and distribution of specific products, the policies of which were generally but not universally accepted. With the advent of the 1914–18 war the industry became a vital instrument for waging it. Individualism had to give way to co-operation in the national interests. The then Minister of Munitions (Mr. Lloyd George) formed an advisory committee of the leading steelmakers to devise ways and means of meeting the rapidly changing demands of the military services for different classes and quantities of products. Efforts were made to ensure that all works concentrated on those products for which they were best suited. Thus was created co-operation between steel companies to meet the nation's need.

I would commence by broadly setting out the position of the industry as it was in 1910. At that time the average number of blast-furnaces in blast was 336, with an annual pig-iron and blast-furnace ferro-alloys output of 10,012,098 tons. The combined coal, and coal equivalent of coke, annual consumption used in operating these blast-furnaces was 20,485,514 tons.

The next year I will take is 1913, the last year before the outbreak of the 1914–1918 war. At that time there were 338 blast-furnaces in operation, with an output of 10,260,315 tons, and a consumption of 21,223,607 tons of coal and coal equivalent of coke. From then on I would refer you to Table I, from which it will be noted that, omitting the war years, the number of blast-furnaces in operation gradually decreased, and by 1932 there were only 65 in operation.

Even if we go back to 1873, the annual output of pig-iron and ferro-alloys was 6,566,451 tons, half the total world production, compared with 3,574,000 tons in 1932, only 9% of world production.

The total crude steel production in 1910 was 6,374,480 tons and, by 1932, it was only 5,261,400 tons (Table II). As against the falling outputs, it is interesting to note how prices had moved during the period (Table III):

	Price per Ton 1913	1932
Cleveland pig iron ...	£2 18s. 10d.	£2 18s. 6d.
Billets (hard)	£6 1s. 10d.	£6 13s. 8d.
Angles	£7 9s. 0d.	£8 7s. 6d.
Heavy rails	£6 13s. 0d.	£8 7s. 6d.

Table I

BLAST FURNACES, PIG-IRON* PRODUCTION, AND RAW MATERIALS CONSUMPTION, 1873, 1910–1933
Excluding War Years

Year	Average No. of Furnaces in Blast	Pig-Iron Made, tons	Iron Ore Smelted, tons	Coal Used, tons	Coke Used, tons
1873	683	6,566,451	16,820,035	16,718,532†	...
1910	336	10,012,098	24,864,109	20,485,514†	...
1911	320	9,526,272	23,712,131	19,218,491†	...
1912	312	8,751,464	21,958,969	17,997,854†	...
1913	338	10,260,315	25,707,518	21,223,607†	...
1918	318	9,107,384	22,544,064	2,606,840	11,286,680
1919	280	7,417,401	19,044,272	2,309,587	9,384,337
1920	285	8,034,717	19,137,460	2,062,360	10,036,210
1921	95	2,616,300	5,604,093	651,077	3,075,947
1922	132	4,902,300	10,230,972	948,361	5,819,084
1923	203	7,440,500	16,493,800	1,702,400	8,645,700
1924	186	7,307,400	16,880,500	1,375,566	8,608,890
1925	152	6,261,700	14,811,000	885,800	7,465,600
1926	69	2,458,200	5,715,600	282,400	2,955,500
1927	168	7,292,900	16,967,400	1,093,300	8,404,200
1928	143	6,610,100	15,666,200	847,300	7,696,600
1929	158	7,589,300	18,268,000	734,900	9,009,400
1930	125	6,192,400	15,330,800	494,500	7,380,100
1931	74	3,772,600	9,591,600	94,800	4,608,800
1932	65	3,574,000	9,044,700	30,000	4,282,800
1933	72	4,136,000	9,919,400	76,500	4,758,500

*Includes blast-furnace ferro-alloys †Includes coal equivalent of coke

Covering the same period, it is important to examine the import and export figures and price changes (*see* Table IV), as these have a vital bearing on the well-being of the whole industry:

	Imports	Exports
1910	1,367,340 tons	4,588,009 tons
1913	2,230,955 ,,	4,969,225 ,,
1927	4,406,089 ,,	4,196,206 ,,
1932	1,593,555 ,,	1,887,295 ,,

From these figures we see that in 1910 the industry was producing 10,012,098 tons of pig iron and 6,374,480 tons of crude steel and, at the same time, only importing 1,367,340 tons, while exporting 4,588,009 tons of iron and steel products. By 1928, however, just before the world trade slump hit all industries, we were producing only 6,610,000 tons of pig iron; although production of crude steel had risen with world recovery to 8,519,700 tons, our iron and steel exports were 300,000 tons less and we had allowed our imports to rise to 2,897,000 tons—an increase of over 1½ million tons; in 1927 they had even risen to 4·4 million tons.

In 1929 came the disastrous world collapse of trade, starting in the U.S.A., to produce the acute economic depression of 1931–2. World production of iron and steel fell by about 50% between 1929 and 1932, and this country shared in the drop. Our exports fell between 1929 and 1931 by 2·4 million tons, but imports remained almost stationary, while prices fell, for some products, even below the 1913 level.

It is therefore with this background of falling home production and increasing imports, rising costs, and very small increases in selling prices that we consider the history of the steel industry. The effect was nothing less than catastrophic.

In 1910, foreign competition, particularly in the field of sheet bars and billets, was such that few British firms found that they could do more than hold their own. By 1913 we were already importing nearly 1 million tons of semi's.

Then came the war, and the price of No. 3 Cleveland pig iron jumped from £2 18s. 10d. per ton in 1913 to £10 9s. 3d. in 1920, and back again to £4 10s. 8d. in 1922 ; billets from £6 1s. 10d. to £22 17s. 6d. and back again to £8 0s. 0d. ; tinplate bars from £5 4s. 0d. to £24 8s. 6d. and back to £7 7s. 3d. ; heavy rails from £6 13s. 0d. to £23 4s. 9d. and back again to £9 4s. 2d. ; angles from £7 9s. 0d. to £23 2s. 0d. and back to £9 7s. 8d. and ship plates from £7 17s. 9d. to £23 15s. 0d. and back again in 1922 to £9 18s. 4d. (*see* Table IV).

It might be thought from the 1920 figures that the

Table II

PIG IRON, FERRO-ALLOY, AND STEEL PRODUCTION 1910–1933
Excluding War Years

Year	Pig-Iron and Blast-Furnace Ferro-Alloys, tons	Steel Ingots and Metal for Steel Castings, tons
1910	10,012,098	6,374,480
1911	9,526,272	6,461,610
1912	8,751,464	6,796,100
1913	10,260,315	7,663,870
1921	2,616,300	3,703,400
1922	4,902,300	5,880,600
1923	7,440,500	8,481,800
1924	7,307,400	8,201,200
1925	6,261,700	7,385,400
1926	2,458,200	3,596,100
1927	7,292,900	9,097,100
1928	6,610,100	8,519,700
1929	7,589,300	9,636,200
1930	6,192,400	7,325,700
1931	3,772,600	5,202,600
1932	3,574,000	5,261,400
1933	4,136,000	7,024,000

Table III

AVERAGE PRICES OF CERTAIN IRON AND STEEL PRODUCTS, 1913–1933
Prices per ton (last week of each month)

Year	No. 3 Cleveland Pig-Iron	Billets Hard	Tinplate Bars	Rails (Heavy)	Angles	Ship Plates (English)
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1913 (Av.)	2 18 10	6 1 10	5 4 0	6 13 0	7 9 0	7 17 9
1920 (Av.)	10 9 3	22 17 6	24 8 6	23 4 0	23 2 0	23 15 0
1922 (Av.)	4 10 8	8 0 0	7 7 3	9 4 2	9 7 8	9 18 4
1923 (Av.)	5 10 7	10 1 2	9 0 1	9 9 10	9 11 9	10 1 2
1924 Jan.	4 19 0	10 5 0	8 18 9	9 10 0	10 0 0	10 10 0
1924 July	4 6 6	9 10 0	8 12 6	9 0 0	10 0 0	10 5 0
1925 Jan.	3 19 0	9 5 0	8 7 6	9 0 0	9 5 0	9 15 0
1925 July	3 11 0	9 0 0	6 12 6	8 10 0	8 5 0	9 0 0
1926 Jan.	3 10 0	8 2 6	6 2 6	8 0 0	7 5 0	7 17 6
1926 July	4 10 0	8 2 6	6 5 0	8 0 0	7 7 6	8 2 6
1927 Jan.	4 5 0	8 2 6	6 15 0	8 10 0	7 17 6	8 17 6
1927 July	3 10 0	8 2 6	5 15 0	8 2 6	7 12 6	8 7 6
1928 Jan.	3 5 0	8 2 6	5 15 0	8 7 6	7 12 6	8 7 6
1928 July	3 6 6	7 12 6	6 0 0	8 10 0	7 17 6	8 7 6
1929 Jan.	3 6 0	7 15 0	6 0 0	8 10 0	7 17 6	8 12 6
1929 July	3 12 6	8 2 6	6 10 0	8 10 0	8 2 6	8 17 6
1930 Jan.	3 12 6	8 0 0	6 5 0	8 10 0	8 7 6	8 17 6
1930 July	3 7 6	8 0 0	6 0 0	8 10 0	8 7 6	8 17 6
1930 Dec.	3 3 6	7 10 0	5 12 6	8 10 0	8 7 6	8 17 6
1931 (Av.)	2 18 6	6 15 11	4 19 6	8 7 8	8 7 6	8 16 3
1932 (Av.)	2 18 6	6 13 8	4 15 6	8 7 6	8 7 6	8 16 3
1933 (Av.)	3 2 6	6 17 11	4 17 6	8 7 6	8 7 6	8 16 3

steel industry must have done exceedingly well financially as the result of the war and post-war boom ; the results were quite the contrary. War prices were inevitably affected by the economic conditions imposed by war, entirely beyond the control of the industry or even the Government. For example, marine insurance rates soared ; the rate per ton of iron ore from Spain rose to £5 and comparably on all imported materials. In the case of pig iron the Government paid a subsidy to the makers of £3 per ton and thus reduced the price to the consumers. As a consequence, the famous sliding scale regulating the wages of iron and steel workers on the basis of averaged selling price changes of standard products had to be abandoned, with the assent of the workers, and a cost of living scale was substituted (Table X).

In the last war controls and price fixing were applied in one way or another to all industries, so as to keep the price as low as possible to the consumer. In the First World War, owing to general urgency and lack of experience, a greater measure of improvisation was necessary, and the controls and price fixing were largely based on ascertained costs plus 10% profit.

The Government relied on the Munitions Levy and Excess Profits Duty. Early on, the Excess Profits Duty was fixed at 80% of the profit made in any one year in excess of the average annual profit of the three years immediately preceding the war. The result was that in all industries, including the steel industry, costs and selling prices of all products rose month by month, and as the war progressed the prices rose even more steeply. This continued even after 1918 until 1922, owing to the speculative user accumulating stocks in anticipation of the expected post-war demand.

Almost overnight at the end of September, 1920, the world slump struck the steel industry, together with all other industries. The Dow Jones American indices of industrial stocks showed that the average on Wall Street came down to 70; to-day it is around 400–415.

Prices of raw materials, such as scrap, pig iron, etc., fell day by day. There was nothing the steel industry could do about it: the value of their raw materials in stock, work-in-progress, and finished stocks was more than halved in a matter of weeks. In 1921 the production of pig iron and blast-furnace ferro-alloys fell to 2,616,300 tons and that of crude steel to 3,703,400 tons (Tables VI and VII).

All this resulted in all steel companies incurring very severe financial losses and as a result they were so crippled as to prevent the carrying out of research, development, modernization, or erection of new plant, for which many had planned and which both the interests of the industry and of the nation required.

The years from 1921 to 1931 were rightly called " the black decade "; it was a time of extreme anxiety to all those engaged in the steel industry, whether they were high executives, staff, or workpeople. During one period (1926–1927) 45% of the workers registered in the industry were unemployed. These were indeed dark days of unemployment or short time, long to be remembered by all those working in the industry. Many firms in the following years were forced by circumstances to write down the value of their equity shares and have a scheme of financial reconstruction. No less than £35,000,000 was written off during this period.

As a result of the dislocation of the industry and the interlocking with the Ministry of Munitions through price regulations and subsidies, and the necessity for devising a means of reverting to peace conditions with the minimum of disturbance to post-war recovery, the President of the Board of Trade

Table IV

IMPORTS AND EXPORTS OF IRON AND STEEL AND MANUFACTURES THEREOF, 1910–1933

Excluding War Years

Year	Imports		Exports	
	Tonnage	Value	Tonnage	Value
1910	1,367,340	£9,806,214	4,588,009	£42,976,671
1911	1,761,958	£11,133,854	4,515,905	£43,730,292
1912	1,995,570	£12,957,875	4,807,528	£48,597,677
1913	2,230,955	£15,889,963	4,969,225	£55,350,747
1921	1,640,024	£22,887,372	1,696,889	£63,603,550
1922	881,284	£10,419,428	3,397,185	£60,861,674
1923	1,322,137	£13,772,873	4,317,537	£76,155,978
1924	2,429,385	£22,387,124	3,851,435	£74,534,129
1925	2,719,779	£23,992,169	3,731,366	£68,178,462
1926	3,737,092	£29,512,158	2,987,930	£55,060,875
1927	4,406,089	£34,032,026	4,196,206	£69,383,416
1928	2,897,240	£24,147,792	4,260,462	£66,789,184
1929	2,822,282	£24,690,225	4,379,541	£68,002,782
1930	2,912,113	£23,298,894	3,159,661	£51,261,119
1931	2,844,814	£19,621,620	1,978,958	£30,375,155
1932	1,593,555	£8,662,473	1,887,295	£28,040,810
1933	970,830	£6,122,408	1,921,794	£29,879,132

had set up a committee of steelmakers and others to examine the position of the iron and steel industry after the war. The Chairman was Mr. G. Scoby-Smith, of Bolckow Vaughan. The Committee reported at length in 1917. Although the majority recommendations were not adopted in time to achieve their immediate object, ultimately, during the ensuing 15 years, most of them, including protection of the home market, were adopted. The Government pointed out to the Steel Committee of the Ministry of Munitions that they must provide a body who could represent the industry as a whole, with whom negotiations could be conducted to settle the mutual liabilities of the industry and the Ministry of Munitions, and the adjustment and ultimate removal of subsidies, taking over of stocks, and so forth, so as to cause the minimum of disturbance to post-war recovery.

Consultations between the individual steel companies soon indicated to some of the larger companies that the problems of the post-war world, apart from relations with the Government, could only be solved by collaboration. Most felt that this necessitated the provision of a forum for continuous discussion of the problems involved in the relation of the industry to the national economy, although others wished to revert to pre-war conditions with the greatest freedom possible for competition between themselves.

The steelmakers formed the National Federation of Iron and Steel Manufacturers, which opened its offices at Temple Bar House, Strand, on 11th November, 1918 (Armistice Day). Mr. Walter (now Lord) Layton was appointed the first Director. He had been responsible for statistics in the Ministry of Munitions. He organized a small but very effective statistical department (which has expanded since that day to meet the growing needs of the industry), and thus provided the Federation with the basic knowledge necessary for effective negotiations with the Government.

Mr. Layton was called away to assist at an international conference and, after some 18 months, resigned when Sir William Larke was appointed Director and assumed office in September, 1922.

At this time—1922—what was the situation? Output of pig iron was 4,902,300 as against 10,260,315 tons in 1913; output of crude steel 5,880,600 as against 7,663,870 tons in 1913 (Tables VI and VII).

Developments in the war years were of necessity limited to war needs and not necessarily best suited to peace conditions. Under these post-war conditions development had been slow; for instance, though there were 546 open-hearth furnaces in 1913 averaging 40 tons per heat, by 1928—the year before the world slump of 1929–1930—there were 615 open-hearth furnaces but with only an average of some 53 tons per heat (Table VIII).

This small rate of progress in the increase of the size of steel furnaces was in spite of the fact that, during the war, several steelworks expansion schemes were undertaken by large firms: to mention some—Dorman Long, Bolckow Vaughan, John Summers and Sons, where improved steel furnaces both in size and performance were built.

Other expansion schemes were undertaken by most companies in the industry, and it was stated in Parliament that some 40 contracts for new steelworks extensions were outstanding in November, 1918. Owing to war conditions there were always two limiting factors as to what might be done:

(i) The availability of labour and materials

(ii) The need for speed of installation, which called for the use of existing practice.

The net result was that, broadly speaking, in the war period expansion was rather one of adding to existing plant and, though the units added were on the whole good, there was not much done, for example, in the way of close integration of fuel resources.

The blast-furnace story is little different. In 1913 the average number of blast-furnaces in blast was 338, with an output of 10,260,315 tons, or an average of 30,350 tons per year per furnace, and in 1928, the average number in blast was only 143, with

an output of 6,610,000 tons, or an average per furnace of 46,200 tons per year.

In considering the increase in the annual figure per furnace, it must be remembered that in blowing out blast-furnaces it would be the smaller ones that would be put out of commission first.

Fuel in the form of coal and coke had been abundant and cheap. Coke was delivered to furnaces at 20s. to 25s. per ton and in some places during the slump at 10s. per ton, for which it could not be produced.

In 1924 a Fuel economy committee was set up by the Federation, with Mr. M. Mannaberg as Chairman and Mr. E. C. Evans, F.R.I.C., as Technical Officer. At that time it was stated to the first Coal Commission (Lord Sankey, *Chairman*) that the equivalent of 4½ tons of coal were used to produce one ton of finished steel. Within three to four years the technologists in the industry, as the result of study and pooling the experience within the industry, had reduced this to 2½ tons. To-day it is under 2 tons.

Within a few years, the Fuel committee, having extended its interest to scientific and technological research into the processes of the industry, and as a result generally promoted interest and co-operation within the industry, was absorbed by the Iron and Steel Industrial Research Council. The members of the Council were mainly nominated by the Federation and this Institute; a few others represented allied interests and the Department of Scientific and Industrial Research.

Under the Iron and Steel Research Council committees were set up to deal with specific subjects. Grants were made to Universities and research organizations to enable them to investigate problems for which they were particularly equipped. Thus the leading scientists of the country were enlisted to direct research into problems of which they had special knowledge—generally allied to work on which they were engaged. Their services were honorary, the cost being that of payment of investigators and apparatus. Every University in the United Kingdom with suitable research facilities was enlisted in this work and received grants. Expenditure reached £80,000 per annum by 1946, when the British Iron and Steel Research Association was formed, and an accumulated capital reserve of £142,000, together with staff and programme, was transferred to it. This is a separate autonomous body with its own laboratories and an expenditure of some £500,000 per annum, and B.I.S.R.A. is now the largest co-operative research association in the country. It receives a substantial grant from public funds through the Department of Scientific and Industrial Research, but is mainly financed by the industry through the Federation.

After the 1914–1918 war the steel industry faced competition with much increased capacity and rather better equipment, but was also in many cases carrying very heavy debenture charges and at a high rate of interest, as instanced in the case of Bolckow Vaughan and Co., Ltd., who in 1923 raised debentures at 6% as compared with a Bank Rate of 3/4% (Table IX).

The industry was caught in a vicious spiral of diminishing markets at home and abroad, rising imports, rising costs due to running short time, with resultant low profits or even losses, made worse by the calamitous General Strike and coal strike in 1926, which put the recovery of industry back again.

Table V

EXPORTS OF TINPLATE AND SHEET FROM THE U.K., 1910–1933

Year	Tinplates, tons	Galvanized Sheets, tons	Black Sheets under ⅛-in., tons
1910	482,981	596,949	73,602
1913	494,497	762,075	68,152
1927	472,016	772,828	262,986
1929	580,766	711,700	281,785
1930	508,233	431,743	184,047
1933	453,245	275,797	125,348

In May, 1921, a memorandum was presented to the Government (Prime Minister, Mr. Lloyd George) when the relative weakness of the British industry was traced to circumstances outside its control, i.e. it was up against imports produced in countries on the Continent with cheap labour (wage level under 50% of that in the U.K.) due to a lower standard of living, lower capital charges due to currency devaluation or reparations, lower taxation, railway rates subsidized by their Governments, and the advantage of an abundant supply of cheap scrap resulting from the war. To this was added the disadvantage due to the foreign exchange position.

Great Britain adopted deflation in 1920, and returned to the Gold Standard in 1925. The return to the Gold Standard created a new series of trade difficulties. From 1922 onwards some 90% of the steelmakers, who were not dependent on cheap imported semi-finished materials, were convinced that protection for the home market was essential for survival if our standard of living was to be maintained.

It was at this stage that Sir William Larke became the energetic protagonist with the Government and throughout the country for a home market protected from dumping by a tariff. With a tradition of 80 years' prosperity under free trade, public opinion had to be convinced of the necessity of the change under changed world conditions. Year by year this fight went on, most ably fought by Sir William, although with little or no effective result for the time being. In 1929 world trade entered another colossal slump, in magnitude and area never experienced before, which of course included the steel industry. World steel production was halved between 1929 and 1931.

At the beginning of 1930, two things took place of major importance. The first was the Report of the Sub-Committee of Civil Research, which was presided over by Lord Sankey. There had been two previous major enquiries into the iron and steel industry—the Balfour Committee on Industry and Trade and a Cabinet Committee presided over by the Prime Minister (Mr. Baldwin), which met fortnightly for six months but published no report—making three investigations in two years. The Sub-Committee of Civil Research judged that the smelting and coke-making branches of the industry were wholly antiquated and inadequate, and ore mining and steel-making less so but still in need of great expenditure.

Table VI

PRODUCTION OF PIG IRON* BY DISTRICTS, 1913–1933
In thousands of tons

District	1913	1920	1924	1929	1933
1. Derby, Leicester, Notts, Northants	1166·1	914·4	1102·5	1174·2	750·2
2, 3, and 9. Parts of Lancashire and Yorks (including Sheffield)	503·5	591·6	570·5	472·4	222·2
4. Lincolnshire	450·0	589·2	656·7	864·7	609·4
5. N.E. Coast	3869·0	2638·6	2246·7	2349·1	1063·1
6. Scotland	1369·2	902·5	667·8	607·1	219·8
7. Staffs, Salop, Worcester, and Warwick	850·7	697·2	482·0	439·9	307·2
8. S. Wales and Mon.	889·2	692·0	865·6	926·5	451·4
10. N.W. Coast	1162·6	1009·2	715·6	755·4	512·7
Total	10,260·3	8034·7	7307·4	7589·3	4136·0

*Includes blast-furnace ferro-alloys

All told, £15,000,000 at least, and probably much more, would be needed to restore the technical efficiency of the industry. Expenditure was apportioned to:

20 new blast-furnaces to make 400 tons per day each, at a total cost of £8,000,000

160 steel furnaces to be modernized, at a total cost of £5,000,000

5 new coking plants urgently needed to make 25,000,000 tons of coke, at a total cost of £4,000,000.

The Committee did not believe there need be any difficulty in obtaining the capital required, as it had consulted the Governor of the Bank of England who had declared that the money for reorganization could doubtless be found, provided that the proposals were technically and financially rational.

The Committee did say that when the British industry had renewed its youth, dumping might still make it unprofitable. If this occurred and reconstruction miscarried, then protection might be invoked.

The second important event was that the large basic industries, including the steel industry, were powerless to raise sums of money even if the individual firms wished to do so, and it was because of this that the Governor of the Bank of England formed the Bankers Industrial Development Company. This was a non-profit-making company formed to receive and consider schemes submitted by the basic industries of Great Britain for the purpose of their rationalization, either by industries or by regions.

As an indication of the importance attached to the formation of the Bankers Industrial Development Company, the names of the forty-five shareholders included the Bank of England and twenty joint-stock banks—eleven England, eight Scottish, and one Anglo-Irish (the National Bank)—and twenty-five financial houses of various types. These might roughly be classified as thirteen issuing houses, seven acceptance houses or merchant bankers and three investment houses.

The capital was £6,000,000 and with this it was able to finance schemes in their early stages, up to a time when a public issue could be made and the loan paid off. A good example is the Stewarts and Lloyds Corby scheme : Stewarts and Lloyds were able to borrow the money as and when required and then at a later date made a public issue and paid off the Bankers Industrial Development loan, when the repaid money was available to finance further schemes. It may well be said that the Bankers Industrial Development Company was the pilot plant and forerunner of the Finance Corporation for Industry, which was formed in 1945 to finance schemes on a larger scale over a wider field of operation. It has financed many large schemes of development in the steel industry.

It is one thing for financial facilities to be made available, but for industrial undertakings to be able to borrow money they must be credit-worthy, and an undertaking cannot be credit-worthy unless the industry it is, or will be, engaged in is a healthy industry, with the prospects of earning reasonable profits.

Reverting to the steel industry, we find that in spite of all representations made to the Government of the day, the industry was without any security in its home market.

In a report on the structure of the iron and steel industry incorporating plans for rationalization in December, 1930, I set out the following recommendation:

> " Finally, in order that the future of the Iron and Steel Industry may be planned and developed on the best and most efficient lines to the benefit of both the Steel producer and the user of his semi-finished product, the Industry should set up an Advisory Steel Production Council.
>
> The Council should be composed of representatives of the four Regional District steel producing combines, together with Consett Iron Co., Stewarts and Lloyds (representing the Steel Tube Industry), the Galvanized and Black Sheet Industry, Tinplate Industry and Wire Drawers, Re-rollers and Steel Forging and Armament Industry.
>
> The chief object of the Council should be to maintain a constant review of the general activities and production of all sections of the Iron and Steel Industry and, in the light of such information and in the best interests of the Industry, the efforts of the Council would be to help co-ordinate and adjust iron and steel capacity and future developments as between Regional Districts, taking into consideration production costs, home and foreign markets.
>
> When reviewing capacity and future developments, special consideration should be given to the needs, supplies, etc., of the finishing trades, who use as their

Table VII

PRODUCTION OF STEEL INGOTS AND CASTINGS BY DISTRICTS, 1913–1933
In thousands of tons

District	1913	1920	1924	1929	1933
1. Derby, Leicester, Notts, and Northants 2 and 3. Lancs. other than 10 and Yorks. other than 5 and 9	511·9	954·9	852·7	771·9	631·7
4. Lincolnshire	241·4	329·8	466·1	733·5	703·1
5. N.E. Coast	2031·1	1950·8	1717·2	2208·3	1317·4
6. Scotland	1430·8	2074·4	1241·4	1581·6	799·3
7. Staffs, Salop, Worcester, and Warwick	364·8	532·3	487·6	554·9	535·1
8. South Wales and Mon.	1807·3	1884·3	2254·6	2336·1	1769·5
9. Sheffield	878·7	1069·6	1031·1	1217·0	999·5
10. N.W. Coast	397·9	271·2	150·5	232·9	268·4
Total	7663·9	9067·3	8201·2	9636·2	7024·0

own raw material the semi-finished products of the steel maker.

Owing to the repercussion on one area or trade by expansion of production in any other area or trade, it is highly advisable in the national interests as well as in the interests of the Iron and Steel Industry that future developments should not be proceeded with in any piecemeal manner and that before large sums of money are spent on re-organisation, re-equipment and new extensions, a central body should be made aware of the proposals and opportunity given for a thorough investigation and an expression of opinion as to the advisability of the proposed work being carried out.

Unless this is done, new money provided for the Industry may be misspent or the best use not made of it and irretrievable damage done."

Reviewing the period between then and now and in the light of what has taken place since, I may be forgiven for thinking that these recommendations have stood the test of time. It may well be that they had some effect because, early in 1932, the Government set up an Import Duties Advisory Committee under the chairmanship of Sir George May, to consider the conditions under which protection might be granted to British industries and make recommendations to the Government; among their major tasks was a wide survey of the position of the iron and steel industry.

By April, 1932, this Committee recommended the imposition of 33⅓% import duty over a wide range of iron and steel products. This was to be looked upon as an interim measure pending further examination. The May Committee then went on to make an exhaustive examination of the whole industry, trade by trade. After this the Committee reported, as a result of this examination, that "they had come to the conclusion that a grant of protection would not alone suffice to place the industry in a position to play its proper part in the national economy unless it were accompanied by a considerable measure of reorganization."

In June, 1932, Sir George May called a representative meeting of the industry, to which he suggested the appointment of a committee to prepare a scheme of reorganization of the industry's own organization. Arising out of this meeting, the iron and steel industry set up a National Committee and out of that an Executive Committee, with regional committees and sub-committees to consider and make recommendations on the special problems of each section of the industry.

In October, 1932, the National Committee made its first report. The report contained a general statement of the steel situation in the country and avowed the industry's intention to press on with the reorganization of the industry.

About the same date the Import Duties Advisory Committee recommended that the import duty on iron and steel products should be continued for a further two years, subject to satisfactory progress being made on the preparation of the scheme of reorganization and in putting the approved scheme into force.

The steel industry had been given a breathing space and was now able to go to work under much better conditions.

In February, 1933, a scheme of trade reorganization was put before the National Committee and approved. Broadly this included the organization and services created by the National Federation, with the addition of the new sectional trade associations which would be represented on the new Council.

The scheme was to organize the industry on the basis of a number of approved associations each dealing with a separate section of the industry (e.g. pig iron, rolled and re-rolled sheets, etc.), affiliated to the Federation, now in 1934 reconstituted as the British Iron and Steel Federation. These associations, some of which already existed as autonomous bodies, consulting and working generally with the National Federation, were to cover the production of pig iron, ingot steel, steel castings, forgings, special steels, wrought iron, sheets, tinplates, wire, tubes, and fabricated steelwork. Co-ordinating the activities of the associations was the central body, the British Iron and Steel Federation.

The function of the British Iron and Steel Federation was generally to carry on the functions and services of the National Federation, with the additions mentioned on an expanded scale defined in its constitution and articles as follows:

Table VIII

NUMBER OF OPEN-HEARTH FURNACES IN EXISTENCE IN THE VARIOUS DISTRICTS AND TOTAL CAPACITY PER HEAT 1913, 1928, 1929, 1933

District	1913	1928	1929	1933
5. N.E. Coast	125	113	99	97
6. Scotland	115	121	120	112
7. Staffs, Salop, Worcester, and Warwick	32	41	42	40
8. South Wales	113	137	139	111
9. Sheffield	72	104	101	78
Remainder of U.K.	89	99	94	63
Total number	546	615	595	501
Total capacity per heat, tons	21,527	32,865	32,568	29,068

To promote the formation of the associations and to exercise a measure of supervision on matters of general policy.

To prevent unnecessary duplication of plant and to promote desirable amalgamations

To promote extensions and improvements of plant as and when required

To co-operate with affiliated associations in the promotion of the industry's export trade

To take action on behalf of the industry generally in all negotiations and other proceedings with outside interests

To provide services, such as secretariat, trade statistics, and research.

There was to be a National Council and a Central Executive Committee. The Executive Committee was to be presided over by an independent whole-time chairman appointed subject to Government approval.

One of the provisos was that each association was to adopt a constitution, which was to be permanent and should include powers to prevent wasteful competition, while reasonably safeguarding the interests of the members of other associations in the Federation.

It was to secure the progressive concentration of production in the more efficient plants. This meant, where necessary, the elimination of inefficient and redundant plants.

In the case of the steelmakers and rollers, their interest in setting up the Iron and Steel Federation was the continuance of a tariff to assist them by protecting their home market on the condition that they reorganized and modernized their production facilities.

As is always the case in any new movement, there were those firms or individuals who did not like the idea of any centralized organization. This was particularly the case with those who were independent producers of finished products from purchased semi-finished iron and steel. They pointed to the fact that the immediate effect of the 33⅓% import duty had been to deprive them of cheap foreign sources of supply of tinplate and sheet bars and billets and their competitive position in the export markets would depend on the price at which they would be able to obtain the semi's from the other steelmakers and rollers who were members of the Federation.

A scheme of preferential prices for supplies to members of the Federation proved sufficient to obtain the agreement of the majority of those who would wish to hold out against the scheme.

In my Tables I have given the country's output of crude steel from 1910 to 1933, omitting the war years; now I give for comparison the figures for 1934–1936 :

1934	Production rose to	8,849,700 tons
1935	,, ,, ,, ...	9,858,700 ,,
1936	,, ,, ,, ...	11,784,600 ,,

	Imports	Exports
1934	... ... 1,365,989 tons	2,250,176 tons
1935	... ... 1,151,929 ,,	2,368,659 ,,
1936	... ... 1,482,872 ,,	2,234,372 ,,

So it was not until 1935 that steel output was higher for the first time than the record made in 1917 of 9,716,544 tons, and by 1936 the output was increased by a further 1,968,256 tons.

During the period of the depression in the years preceding the granting of an import tariff, as mentioned a good deal of writing-down of capital and reorganization of plants had been going on in many companies: many firms had plans which called for what were in those days considered quite large financial sums.

In Scotland, David Colville and Sons Ltd. had been active in gradually achieving amalgamation with other steelmakers in Scotland with a view to rationalization and achieving increased manufacturing efficiency.

At the outbreak of war in 1914, when the demand for steel rapidly increased, there were actually two steelworks idle—those of The Glengarnock Iron and Steel Company and The Clydebridge Steel Company. David Colville and Sons Ltd. were asked by the Government to endeavour to put these works into operation. There were internal difficulties with these companies and ultimately David Colville and Sons Ltd. in 1915 purchased these two works and immediately began to produce steel for war purposes. In addition, they built alongside each of these works two new steel plants. In 1919, they acquired the sheet works of Smith and McLean Ltd.

In 1930, David Colville and Sons Ltd. entered into an arrangement with James Dunlop and Co. Ltd., whereby the steel works at Calderbank and the blast-furnaces at Clyde Iron Works, with Colville's plant at Dalzell Steel Works and the plants at Clydebridge and Glengarnock, were formed into a new company, i.e. Colvilles Ltd. At Clyde Iron Works, the old blast-furnaces were demolished and new ones were erected with coke ovens and by-product recovery plant. These works being in proximity to Clydebridge Steel Works, the hot-metal system of steelmaking was adopted and the surplus coke-oven and blast-furnace gas was used at Clydebridge Steel Works. At a later date (1936) the works of The Lanarkshire Steel Company Ltd. and The Steel Company of Scotland Ltd. were acquired.

On the north-east coast, Dorman Long and Co., Ltd., had merged in 1923 the interests of Bell Brothers, Ltd., North Eastern Steel Co., Ltd., Sir B. Samuelson and Co., Ltd., and the Carlton Iron Co., Ltd., in the company.

In 1929 Bolckow Vaughan Ltd. was acquired, which gave Dorman Long and Co., Ltd., the controlling interest in Redpath Brown and Co., Ltd. In 1930 Dorman Long and Co., Ltd., acquired The Tees Side Bridge and Engineering Works Ltd.

Like many others as a result of the bad period, Dorman Long and Co. Ltd. had to have in 1933 a financial rearrangement of their capital but, soon afterwards, they made quite a remarkable return to profit-earning, with the result that they were able to restart the plant that was shut down and modernization commenced on a large scale.

The South Durham and Cargo Fleet Companies commenced large extensions and modernizations and soon afterwards erected a complete new mill for rolling sheet bars, billets, and strip. Two blast-furnaces at Seaton Carew were later started up and operations were resumed at their Stockton Wallsend Works.

In the Manchester area, the Lancashire Steel Corporation was formed to take over the iron and steel interests of the Partington Iron and Steel Co. Ltd., the Wigan Coal Company Ltd., Pearson and Knowles Ltd., and Rylands Brothers and, in December, 1932, also acquired the Whitecross Co. Ltd. of Warrington. As a result of this fusion of interests, the Corporation was able to arrange for £1,750,000 new finance for the purpose of modernizing the various works and in particular the Irlam Steel Works. This new finance was made possible by the Securities Management Trust previously subscribing for £500,000 B shares at par in the new company.

The United Steel Companies Ltd. was one of the first to see the benefits of large-scale amalgamation and consolidation. The Company was registered in March, 1918, and the principal undertakings brought together were :

Steel Peech and Tozer Ltd.
Samuel Fox and Co. Ltd.
Appleby and Frodingham Co. Ltd.
Workington Iron and Steel Co. Ltd.
Rother Vale Collieries Ltd.

In 1917 Steel Peech and Tozer had commenced building the Templeborough melting shop and a continuous Morgan billet mill, to produce semi-finished steel in the form of billets and the melting shop to have eleven 60-ton furnaces.

In the same year Samuel Fox became very closely associated with Steel Peech and Tozer. This firm had installed in 1915 a Siemens furnace plant which was again extended in 1917. The next step was to bring into the combine the Frodingham Iron and Steel Co., which was purchased jointly by Steel Peech and Tozer and Samuel Fox and Co. in 1917. The Frodingham Iron and Steel Co. held 50% of the shares of the Appleby Iron Co. and the balance of that Company's shares was acquired shortly after the formation of the United Steel Companies.

The Workington Iron and Steel Co. in 1917 was producing some 250,000 tons of hematite pig iron and about 25,000 tons of basic pig iron. Space prevents elaborating in any detail, but sufficient has been said to indicate what a valuable piece of consolidation and development had taken place. Notwithstanding this, the Company in 1922 suffered the same anxious times as all other companies.

Table IX

BANK RATE, 1910–1933

1910	3%, 5%
1911	3%, 4%
1912	3%, 5%
1913	4½%, 5%
1914	3%, 10%
1915	5%
1916	5%, 6%
1917	5%, 5½%
1918	5%
1919	5%, 6%
1920	6%, 7%
1921	5%, 7%
1922	3%, 5%
1923	3%, 4%
1924	4%
1925	4%, 5%
1926	5%
1927	4½%, 5%
1928	4½%
1929	4½%, 6½%
1930	3%, 5%
1931	2½%, 6%
1932	2%, 6%
1933	2%

In 1929 English Steel Corporation Ltd. was incorporated to take over the steelmaking interests, in Sheffield and Manchester, of Vickers-Armstrongs Ltd. and Cammell Laird and Co., Ltd. In this Company there was thus incorporated the large steel interests built up in the early part of the century by Vickers Ltd., Armstrong-Whitworth and Co., Ltd., and Cammell Laird and Co., Ltd. The Corporation also acquired the share capital of Taylor Bros. and Co., Ltd., Manchester, The Darlington Forge Ltd., Darlington, and Industrial Steels Ltd., Sheffield.

Production was concentrated in the most efficient units in the Group, one of the results of such policy being the development of Taylor Bros. and Co., Ltd., into the largest and most efficient producer of railway tyres, wheels, and axles in the British Empire.

Despite the severe depression in the steel trade which followed the formation of English Steel Corporation Ltd., capital expenditure of over £2,000,000 was authorized, and as a result of this policy the Corporation was in an excellent position to meet the demands arising from the Rearmament Programme which commenced in 1936.

The Park Gate Iron and Steel Co. put down a completely new rolling mill.

The main activities of Richard Thomas and Co., Ltd., were in South Wales, where they owned five steelworks and some 105 tinplate mills and controlled about 35% of the steel and tinplate capacity of the trade. The company also owned the Redbourn Hill works in Lincolnshire and they acquired the Ebbw Vale Steel works with the Irthlingborough ore mines. The Redbourn Hill plant, which was an integrated steel plant for manufacturing sheet and tinplate bars for the Richard Thomas tinplate works in South Wales, had been shut down for some years but, owing to the change in trade conditions, the works were re-opened.

The granting of an import duty gave the confidence

Table X

WAGES AND COST OF LIVING INDICES

	Index of Weekly Wage Rates	Index of Cost of Living
July, 1914	100	100
1914	101–102	...
1915	110–115	123
1916	120–125	146
1917	155–160	176
1918	195–200	203
1919	215–220	215
1920	270–280	249
1921	214	226
1922	176	183
1923	174	174
1924	179	175
1925	180	176
1926	180	172
1927	177	167½
1928	176	166
1929	175	164
1930	174	158
1931	169	147½
1932	168	144
1933	167	140

and security necessary for steel companies to go on with schemes of amortization, reorganization, modernization of old and the building of new plants.

With the return of confidence, these plans began to be put into operation, the outstanding one being the rationalization of all the tube- and steelmaking plants of Stewarts and Lloyds Ltd. which culminated in the proposal to establish an integrated iron and steel and tube-making plant at Corby in Northamptonshire. This scheme was on paper by 1930, but it was not until November, 1932, that Stewarts and Lloyds were able to go on with the erection of the plant, the necessary preliminary finance—some £3,500,000—being arranged through the Bankers Industrial Development Company. This was only looked upon as a beginning of the Stewarts and Lloyds development at Corby. This has since proved to be so, and in fact the original plant has been more than doubled in the intervening years.

The Guest Keen and Baldwins Iron and Steel Co., Ltd., was an amalgamation of the Cardiff steelworks of Guest Keen and the Port Talbot Steelworks of Baldwins. As a result of this amalgamation of interests and the formation of the new company very considerable schemes of rationalization of steel products within the company were made, and at Cardiff a new steelworks, cogging mill, billet mill, and mill for rolling small rounds and merchant bars were erected. The necessary finance (some £3,000,000) was made available by the Bankers Industrial Development Co., Ltd.

Concurrently with and alongside the erection of the Guest Keen and Baldwins Steel Works, the installation of a new semi-continuous wire-rod mill and strip mill was commenced by Guest Keen and Nettlefolds Ltd. to replace their old works at Rogerstone. This was followed by the installation of an entirely new wire-drawing department and wire-nail department. All these departments provided greatly increased outputs compared with the old units.

The Whitehead Iron and Steel Company put down a new continuous mill at Newport for rolling merchant bars, rounds, and ferro-concrete bars.

The Briton Ferry Steel Co. put down a complete new bar mill for rolling sheet and tinplate bars, but this was not completed until early 1936.

I have given some instances of the type of improvement and expansion that had taken place, much of which was made possible by the improvement both in the country's trade in general and the steel trade in particular.

To summarize

(1) There were two complete new steelmaking plants at Corby and Cardiff

(2) Enlarged capacity and improved efficiency at the works of Dorman Long, Cargo Fleet and South Durham, and Colvilles.

(3) Modernized and enlarged blast-furnaces, together with a new acid Bessemer plant, at Workington by the United Steel Companies

(4) Increased capacity at the United Steel Companies' works at Templeborough for billets, and also the use of the capacity of their Appleby Plate Mill. The mill had never worked more than 40% since it was built until the later years.

I have only given a few examples to indicate what was taking place in all steel companies in some form or other, either in major schemes or in minor schemes for increasing efficiency. The sum and total of the amount spent in these years, 1931–1935, was some £25,000,000.

It is entirely due to the enterprise and courage of all concerned in undertaking this reorganization at this time that the iron and steel industry was able to meet war demands in the years 1939–1946 in such a large measure as to form the material basis of the British contribution to the victory of the Allies.

And now let us consider what has taken place in the industry from 1910 to 1935 and try to draw some conclusions as between cause and effect.

From 1910 to 1933, except for the war years, we see a gradually declining British steel industry with imports of steel rising and exports falling, owing to our previous markets and sources of supply of imported raw materials becoming more and more industrialized and self-sufficient, particularly as regards iron and steel.

Except for the war years and the short boom period afterwards, there was a general feeling of frustration in those employed in the steel industry. Profits were low or non-existent, with the result that money was not available, nor was it worth while from a financial aspect for firms to spend the money that should have been spent on building new plants or to spend the sums that should have been spent on keeping thoroughly up-to-date.

On the technical side, it was The Iron and Steel Institute that took the initiative in organizing research committees. The Institute had from its foundation in 1869 published papers describing

progress in the science of metallurgy governing the physical properties of the products and the technique of production, and arranged discussions on these papers and on scientific and technical problems of common interest. The effect of this was to break down the barriers which had tended to prevent a free interchange of information between those who participated in the Institute's meetings.

War demands gave a great impetus towards freer exchange of views, experience, and information. In 1917, The Iron and Steel Institute set up five Research Committees on :

(1) Ores, fuels, and refractories
(2) Blast-furnace practice
(3) Steel and its mechanical treatment
(4) Iron and steel foundry practice
(5) Metallography, chemistry, and physics.

Looking back, it would appear that the determination of the best current practice was of greater interest than improvement on this practice. Much good work was done, but the technique of co-operative research had not been worked out. The four Committees on iron and steelworks practice ceased to meet after 1921, though the fifth committee, on metallography, chemistry, and physics, continued to meet until 1929. It was this committee which was the parent of the Committee on the Heterogeneity of Steel Ingots. This had originally been set up in 1924 as a sub-committee, but on the winding up of the No. 5 Committee assumed independent status under the Iron and Steel Industrial Research Council. Under the able guidance of the late Dr. W. H. Hatfield, F.R.S., as Chairman, it became the industry's first really successful co-operative research committee. Much good work was done and the nine reports published by the Institute up to 1939 are still looked on as classics in the development of the knowledge of the structure of steel and of steelmaking.

In 1927 a renewed attempt was made to establish co-operative research and four committees were set up :

(1) Coke-oven plant and practice
(2) Blast-furnace plant and practice
(3) Steel-furnace plant and practice
(4) Rolling-mill plant and practice.

These four technical committees continued to meet until 1928–1929, when the organization was changed by the formation of the Iron and Steel Industrial Research Council in 1929. This was the forerunner of the British Iron and Steel Research Association. Under its general control the Institute organized a series of Joint Research Committees and Sub-Committees with the Federation—some very successful in helping Technical Committees dealing with blast-furnace, open-hearth, rolling mills, and similar aspects of production.

After that the informal division of responsibility adopted was that the process of manufacture and technique of production were for the Federation and that Committees dealing with the product and problems of scientific and fundamental nature were still organized by the Institute.

Though research and development were being steadily organized and expanded, it would be true to say that they were hampered by lack of necessary finance and full and unrestrictive co-operation as we know it to-day. Much first-class work was done and the records of the papers submitted to the Institute are there as evidence.

In 1933 a general improvement in trade after the catastrophic slump which had started in 1929 was beginning and the steel industry benefited from this, but (what was even more important) it had by means of an import tariff secured a much needed productive load on the works. At the same time the Import Duties Advisory Committee had made it a condition that, in return for their recommendation to the Government for import duties, the industry must modernize their plants. All sections of the industry must develop to the greatest extent possible their co-operation to avoid duplication of new plant, and extend joint selling where necessary in the export markets and expand their joint research.

This was only emphasizing what the industry through the Federation had been doing in research, development, and in export markets—joint selling to a considerable extent. Equally if not more important, there was existing very full co-operation in productive efficiency by exchange of information, costs, and visits to competitors' technologists and works, thus raising the standard of efficiency of the industry as a whole.

One lesson to learn is that whilst it is necessary for the steel industry to do all within its power to improve its efficiency and keep up to date, it cannot prosper unless the trade conditions are such that the whole country is also prosperous—and, owing to its basic character and dependence on other industries and services, they must also be efficient and kept up to date.

There is another lesson that has not yet been mentioned but which would seem to be of first importance. It is the serious effect of panic resulting from a general slump in the price level. Prices continued to fall and producers tended to follow them down to keep works going until they were lower than actual costs.

It was at this stage that the iron and steel industry determined to fix minimum prices which would cover full costs. This had a remarkable effect in creating first a small and then an ever-increasing area of stability in the price level in this country and, by its influence, in Europe, since all the industries and services on which the iron and steel industry is dependent were able to follow suit. When the decline was checked the basis for recovery had been created.

In the early period of the years of my review, we had a vicious circle of lower outputs, lower employment, and lower profits followed by consequent insufficient capital expenditure on new plant. Each of these factors reacted on the other so much that the position gradually got worse and worse. During this period we were also faced with the pound going off the Gold Standard.

Though the industry got to the brink of the precipice, general trade conditions, together with the application of an import tariff, created conditions within which the industry could gradually recover its efficiency and solvency.

It is not my intention to carry on from this point

to what has since taken place. It is from this comparatively recent date that the march of events—expanding production, the building of new large integrated steelworks, the ever-increasing markets, particularly in flat steel products, the tremendous increase in expenditure on research and development, with the resultant remarkable improvement in efficiency in all departments of the industry—is known to most of you.

It is difficult to say what is the value to be placed on any one factor or which relatively comes first, but there are certain essentials for the prosperity of our industry :

A general condition of prosperity at home and abroad ; we cannot prosper in isolation

Our home market should continue to receive such protection as is necessary to allow for the maximum use of our plants in bad times. To warrant protection we must ensure we have highly efficient plants, which compare favourably with other plants in the world, taking into account any difference in basic economic conditions, e.g. the difference in size and distribution between our home market and that of the U.S.A.

There must be a continued striving for more and more efficient fuel consumption

The efficient use of the available raw materials

The achievement of the highest output possible per unit of capital and per man-hour employed

The constant improvement in the quality of our products.

Obviously all these can only be achieved by efficient management and organization. Constant research and development will be necessary and, furthermore, it is essential that the knowledge gained should be applied at the earliest possible moment ; the time factor is all-important in this increasingly competitive age.

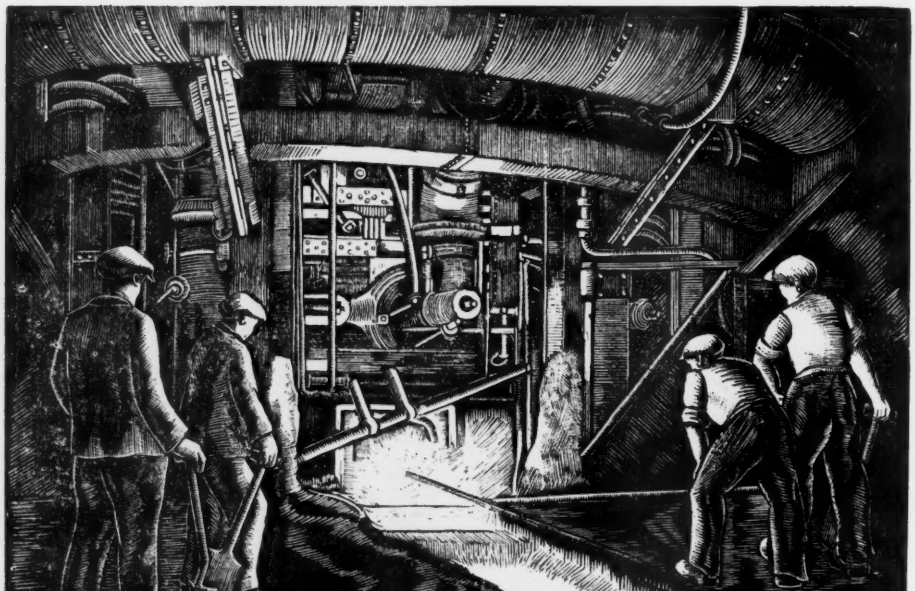
Never let us forget that research and the application of the knowledge obtained from research is vital to prosperity in a highly competitive world.

It was being first in the field with industrial products that gave us world supremacy in the export trade for almost a century.

I would end by saying that, over and above all the factors to which I have just referred, there is the overriding one of human relationship and co-operation at all levels, only achieved by leadership, both technical and personal, of the highest order.

" It will be enough for me if these words of mine are judged useful by those who want to understand clearly the events which happened in the past and which (human nature being what it is) will, at some time or other, and in much the same ways, be repeated in the future."

Thucydides: *The Peloponnesian War*



Running liquid iron from a blast-furnace (from the original woodcut by Viva Talbot)

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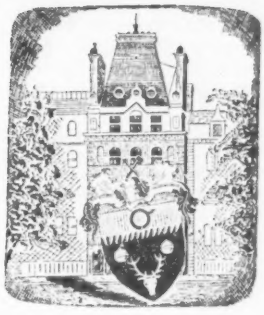


The Institute's Special Meeting in Sweden, 1954

A SUMMARY

References to the Special Meeting held in Sweden by invitation of Jernkontoret in June, 1954, are scattered through various issues of the *Journal* and so it is thought that the following summary may prove useful. Some new information has been added to make the record more complete.

A SHORT GENERAL ACCOUNT of the meeting was published in the *Journal* for September, 1954. Of greater interest is the magnificent paper on "Iron and Steel Making Processes Used in Sweden," by Sven Fornander, Director of Research for Jernkontoret, which was published in May, 1954. Other British and Swedish papers specially written for the meeting were published in April and May, 1954. Summaries of the discussions on those papers which were presented at the Institute's Annual General Meeting in London in May, 1954, and at the Joint Meeting with Jernkontoret in Riksdagshuset, Stockholm, on 12th June have been published in the issues of the *Journal* for October and December, 1954 (Structure of Cast Irons; Rolling Mills), February, 1955 (Properties of High-Purity Alloys), and March, 1955 (Pelletizing). Notes on Jernkontoret, biographies of Swedish Bessemer Medallists and of authors, and other information were included in the News in May, 1954.

To complete this record of a meeting of outstanding interest, there is now printed a summary of the Presidents' speeches at the Banquet in the Town Hall of Stockholm on 12th June, when the Institute was entertained by Jernkontoret, and extracts from speeches made on other occasions. The transcript of the presentation of the paper by Einar Öhman and J. P. Saville on "The Universal Decimal Classification Applied to Metallurgical Literature"—a paper written jointly by the officials of the two societies who are acknowledged experts in the system of classification which has been adopted in both libraries and adapted for their use by the authors—is printed at the end.

BANQUET AT STADSHUSET, 12th JUNE, 1954

Members and Ladies were entertained by Jernkontoret at a Banquet in the Town Hall on the last evening of the visit to Stockholm, Saturday, 12th June, 1954. Dinner was served in the Golden Hall; afterwards there was a display of gymnastics followed by dancing in the Great Hall; the Galleries and State Rooms of the Municipality were open to those who wished to admire the works of art they contain; stars and lights were reflected in the dark waters of Lake Mälar.

Mr. **Evert Wijkander**, President of Jernkontoret, proposed the toast of the Institute. He said: When in the olden days the Swedish Iron Masters gathered together for festive frolic it was in spacious halls, where many a toast was drunk and many a speech was made. We find, thus, in the old annals that at the dinner given at the conclusion of a session of the Iron Masters' special court in the beginning of the 1850's, no less than twenty-three toasts were drunk, the first of which was dedicated to "His Majesty, our most Gracious Sovereign" and the last to "The common peasantry and the assembled commonalty."

Since then our customs have grown simpler. In this spirit of abstemiousness it has been decided that only two speeches will be made this evening and I hope nobody, having listened to the many and most excellent lectures given by prominent experts earlier to-day, will mind. This reminds me of what Mr. Clement Attlee says in his newly published autobiography: "I did not speak often in the first Session, as the competition from our benches was intense." After so much eloquence earlier to-day it seems wise for us to-night to follow Mr. Attlee's example.

When bidding you welcome—all you guests of Jernkontoret from near and far—I am happy to do so in the City Hall of Stockholm, this creation of an architect of genius, where every detail speaks of the bond between present and past and about the affinity of Swedish culture with that of other countries and peoples.

More than any other industry, perhaps, does the iron and steel trade build upon experience gained by past generations and centuries. At the same time, it is one of the branches of industry where the expansion and technical progress during the last decades have developed most rapidly. Few economic activities have realized the importance of technical research to the same extent as has the iron and steel industry. Since the 18th century,

Jernkontoret has fulfilled a function in this respect both as a leader and as a servant. Gradually, sister organizations have grown up in other countries, among the oldest and most prominent of which is The Iron and Steel Institute, with which Jernkontoret has for many decades maintained a close and friendly and fruitful co-operation.

The rebirth of the Swedish steel industry during the 19th century was to a great extent made possible thanks to methods acquired from Great Britain. At the present time, our British friends' ability to apply the advanced methods of chemistry and physics to the solution of practical problems within our industry is a source of inspiration. On the other hand, it is a great satisfaction to us when Swedish progress receives attention abroad and is exploited practically there. The community of technical research is founded on give-and-take. An atmosphere of generous reciprocity is its vital condition and there cannot be any one-way traffic.

We are grateful to The Iron and Steel Institute for having devoted two issues of their distinguished *Journal* to the presentation to an international public of a series of articles written by Swedish men of science and technical experience. Taken together, these articles provide a picture of the progress of Swedish technique during recent years within the field of iron and steel. We are proud of the fact that during the run of years the Institute has honoured a number of our countrymen with their most distinguished Bessemer medal.

Outwardly, the co-operation between the Institute and Jernkontoret has manifested itself above all by three milestones: the visits of the Institute to Sweden in the years of 1898, 1926, and now in 1954.

Our country as well as industry has passed through great changes during the twenty-eight years that have passed since the Institute last gave us the honour of their visit. In 1898 a small group of nine foreign guests risked the adventure of paying a visit to the newly discovered iron-ore deposits of Kiruna and Luossavaara above the Arctic Circle. Judging from the vivid description in the *Journal*, this was no less fruitful as a venture than it was strenuous and cumbersome as a journey.

The far more numerous group taking part in this year's Lapland excursion will find mines, highly modern well-built communities, roads, and railways where there was wilderness before. We hope they will derive even greater benefit from their excursion than did their predecessors—although somewhat less hardship—even if the millions of Lapland midges might, in their own special way, help to make the experience unforgettable!

Those, also, who start tomorrow their trips to Värmland and Dalecarlia—the classical grounds of Swedish iron and steel—will find how in this century of technical development man has created new values. They will visit new or modernized steelworks, rolling mills, and manufacturing shops. They will also visit sponge-iron plants, the latest development in the Swedish steelmaking industry. However, in spite of this, the description of the poet and historian Erik Gustaf Geijer still rings true to-day although written more than a hundred years ago:

> "My home county has the peculiar advantage of still being—to a great extent—a new country. It is hard to believe that such a long time has passed since the old saga king Olof Trätälja first put his axe to the roots in the forest. He is still there to-day in this land of woods, flowing water, small farms, chalets, remote fishing waters, forest clearings, charcoal kilns, and green paths marking the winter roads of the peasants."

To this country, then, of such endless variety—from the bare mountains and moors of Lapland to the green hills and blue rivers of Bergslagen, to the archipelago of Lake Mälar and the sea—we bid our guests most sincerely welcome.

I am sure that none of the representatives of the non-British nations will mind if I address a special welcome to The Iron and Steel Institute and its President, The Hon. R. G. Lyttelton.

By way of introduction I allowed myself to quote the present Leader of Her Britannic Majesty's Opposition. It seems to me both impartial and fair to seek the support, when concluding, of the Premier in Office, Sir Winston Churchill, who in this Hall half a year ago, represented by his charming wife, Lady Churchill, was feted as the Nobel Prize winner in literature. Unlike Mr. Attlee he spoke frequently during his early days in the House of Commons. The following statement has been recorded from the year 1901:

> "It is known, alike by peoples and rulers, that upon the whole, British influence is a kindly and healthy one and makes for the general happiness and welfare of mankind."

This, it seems to me, may better than anything else express our feelings towards the British Iron and Steel Institute, and I propose that while keeping these words in our hearts we all join in a toast for the welfare of the Institute and its President.

Responding to the toast, The Hon. **R. G. Lyttelton** (President of The Iron and Steel Institute) said: Thank you, Mr. Wijkander, for your splendid speech in beautiful English; I only wish I could return the compliment by replying in your fine Nordic tongue—your language of honour and heroes.

I little thought 28 years ago, the last time The Iron and Steel Institute dined in this noble and romantic hall (which is one of the architectural wonders of the modern world), that on their next visit I should be honoured with the responsibility of returning thanks for your cordial welcome, your inspiring and gracious address, and your generous—nay, overwhelming—hospitality. By all of these you remind us that our two countries and peoples are not only traditional friends, but also collaborators in the development of the arts of peace and the cultural and economic progress of mankind. You remind us also of another happy and outstanding resemblance. We are both royalist peoples, each blessed with royal dynasties deeply rooted in the affections of our peoples, and our affection and loyalty towards our reigning monarchs is strong, deep, and abiding.

On 11th April, 1654, just 300 years ago, a treaty of commerce and friendship was signed between our two countries, between the young Queen Christina of Sweden and the Lord Protector of England, Oliver Cromwell. Except for our treaty of alliance with Portugal, which dates back to the 14th century, this Anglo-Swedish treaty is the oldest unbroken diplomatic link forged by our country, which has helped to bind the two countries together with hoops of iron and with wooden hoops of good Swedish timber.

Ever since those days we have, both of us, faithfully obeyed, with only a few lapses, the first article of that treaty, which ordains that "each party treat and use the other with all real friendship and affection."

There was and is wisdom in that ancient treaty and one recalls the well known remark of your famous Chancellor of those days, Axel Oxenstierna, when he said "You will be surprised, my son, to find with how little wisdom the world is governed." But he did not say this about our treaty.

The modern world, and Britain in particular, owes much to Sweden, for Sweden was the first state to plan commercial and industrial development on a national basis. The famous Stora Kopparberg Company, still of course in active and flourishing operation, which was incorporated in the 13th century, was the first and is the

oldest incorporated company in the world. We like the story—and I know our American friends will like it—of the American firm which not long ago enquired in the ordinary course of business as to the standing of Stora Kopparberg and whether it was an old-established and reliable organization. The reply was "Stora was old, 200 years old, when Columbus discovered America."

For more than 200 years Jernkontoret, our hosts, have regulated the development of the iron industry, and this has exercised a profound influence on the progress of modern iron and steel. Among its members it has, and always has had, several who enjoy a world-wide reputation for their knowledge and their researches, and the central position which it quickly attained in those early days of its existence has grown ever stronger with the passage of time. Long may Jernkontoret prosper for the benefit of all of us who are concerned with steel, and, as you, Mr. President, so aptly remarked, both as a revered leader of our industry and a beloved servant.

Trade between Sweden and our great steel centre of Sheffield is on record as beginning in 1557, but as Chaucer, in his *Canterbury Tales* of 130 years before, mentions a 'whytel,' which is the Saxon for 'knife,' this trading between Sweden and England is probably much older.

Coming to more recent times we like to recall another instance of collaboration, when the great Bessemer, in the middle of last century, was held up in his process of steel production and thought he had failed, though he does not exactly admit that in his diary. It was your Mr. Göranson, assisted as he was technically and financially by Jernkontoret, who enabled Bessemer to triumph by persuading him to double the amount of air he was passing through his iron bath without increasing the pressure—a notable and classic example of collaboration between the two nations.

Thank you, Mr. President, for the reference in your speech to the Nobel Prize winner in literature of last year, Sir Winston Churchill, our greatest living Englishman, whose Nobel Prize was so widely noted and appreciated in England. Sir Winston characteristically expressed the sentiments of our people when he said in this hall through his lady wife "The world looks with admiration, and indeed with comfort, to Scandinavia, where three countries, without sacrificing their sovereignty, live united in their thought, economic practice, and in their healthy way of life." From such fountains new and brighter opportunities may come to all mankind.

We are indeed happy to feel that for so long we have mutually and literally obeyed Shakespeare's famous injunction:

> *Those friends thou hast, and their adoption tried,*
> *Grapple them to thy soul with hoops of steel.*

This occasion is only one more hoop so generously forged by you.

As this is the last time during this visit that we shall all be together, as different parties are joyfully going their several ways to increase their knowledge of your beautiful and interesting country and the activities of its people, may I, in saying goodbye to our generous hosts, remind you of its full meaning—God be with you till we meet again.

DINNER AT GOTHENBURG, 8th JUNE, 1954

Large parties journeyed to Gothenburg in S.S. *Patricia* and S.S. *Suecia*, arriving on Whit Monday; others came by air. Two days were spent in visits to local industries and to the ferro-alloy plants of Ferrolegeringer A.B. at Trollhätten and in sightseeing. Before leaving for Västerås, Surahammar, and Stockholm, Members and Ladies were entertained to dinner by the industrialists of Gothenburg in beautiful Börsen on Tuesday, 8th June. Mr. A. **Gabrielsson**, Managing Director of A.B. Volvo, was in the Chair. In replying to the Chairman's speech of welcome on this, the first formal reunion of the meeting, The Hon. **R. G. Lyttelton**, President, said: I thank you, Mr. Gabrielsson, most heartily on behalf of The Iron and Steel Institute for your delightful speech in beautiful and fluent English, and for your cordial welcome to Gothenburg—to your famous shipyards and engineering works. With your ships, your ball-bearings, and your motor-cars you connect Sweden with all the world and send out that beneficent influence which Sweden radiates with its healthy way of life. In particular I would mention our generous hosts this evening, the world-renowned Götaverken, Volvo, and S.K.F. companies, who opened their gates and their hospitality to us this morning and gave us a most interesting and delightful time, whilst our ladies were enjoying their visit to exquisite Gunnebo with all its British associations.

For many of us this has been our first visit to your historic and beautiful town, now looking its very best, so your visitors say, with its lilac and laburnum and its lovely squares and avenues. For most visitors Gothenburg is the door and gateway to Sweden. It was through Gothenburg that Sir Bulstrode Whitelocke, Cromwell's Ambassador to Queen Christina, travelled to conclude our famous treaty of friendship and commerce exactly 300 years ago last April. How appropriate is the coincidence that we of the Institute are traversing the very road along which ambassador Whitelocke journeyed to Stockholm and Uppsala, though he took rather longer about it than we shall, for better or for worse.

What wisdom and prescience your founder, Gustavus Adolphus, showed in selecting this site for your city at the foot of the hills. And we do like the legend of the small bird, which sought refuge from an eagle at the feet of Gustavus Adolphus while he was standing about here with his retinue; this he treated as an omen, confirming his judgment as to where the town should be built.

Succeeding ages have amply proved how good this omen was, for it has enabled his descendants and successors, with their high technical skill and their energy and character to create a renowned seaport and to place Sweden amongst the first of the shipbuilding and engineering nations of the world. In particular they join that Scandinavian island, Britain, with the present mainland of Scandinavia!

Already in the few hours since we landed we feel that we are not amongst strangers but kinsfolk, as indeed—if I am correct in my historical memory—we certainly are. If anything can enhance our mutual understanding and good fellowship, the generous hospitality that we have received at your hands has created one more tie to bind our two countries together to their mutual advantage.

PRESENTATION TO THE SECRETARY

At a dinner held in Stora Sällskapet, Stockholm, on Thursday, 10th June, after the Reception in Jernkontoret's building, Mr. **Evert Wijkander** said: On this occasion I have a most pleasant duty to perform; His Majesty the King of Sweden has graciously conferred upon Mr. Kenneth Headlam-Morley, Secretary of The Iron and Steel Institute, the insignia of Officer of the Order of Vasa. This distinction is an official Swedish recognition of Mr. Headlam-Morley's laudable contribution—often on the quiet but always efficient—within the framework of the Institute's field of action for the promotion of friendly relations between the British and

Swedish iron and steel industries and for making the Swedish achievements known both in Britain and in other countries. Mr. Headlam-Morley has also, however, during many years personally given assistance to a great number of Swedes visiting Britain. He has, for instance, himself worked out detailed programmes for more than a hundred scholarship students, technicians, and scientists of the Swedish iron and steel industry who have come to Britain for the purpose of study, and he has in a most valuable way introduced them to British circles.

It is a great satisfaction to Jernkontoret, and indeed, to me personally, that you, dear Kenneth, will carry with you from the Institute's meeting in Sweden, to which you have given so much devoted work, this proof of our Sovereign's favour and of the appreciation of official Sweden.

Presentation of a paper on

THE UNIVERSAL DECIMAL CLASSIFICATION

The paper on "The Universal Decimal Classification applied to Metallurgical Literature," by **Einar Öhman** and **J. P. Saville,** was published in the *Journal* for May, 1954. It was presented at the joint meeting with Jernkontoret, held in Riksdagshuset on Saturday, 12th June, 1954. In presenting the paper, Mr. **K. Headlam-Morley,** Secretary of The Iron and Steel Institute, said: During the 40 years from the beginning of the century to the outbreak of war, The Iron and Steel Institute brought together a comprehensive library on all aspects of the manufacture of iron and steel, ferrous metallurgy, and connected subjects. Credit for carrying out the Council's intentions is mostly due to my predecessor, Mr. George Lloyd, and to Mr. R. Elsdon, for many years Librarian and now an Honorary Member of the Institute. Attached to the Library were the information services—such as abstracts, bibliographies, translations, and the rest—which are nowadays taken for granted but which were then by no means so common or so highly developed. The Library and Information Department are now in the efficient care of my colleague, Mr. Alan E. Chattin.

After the war, the problems of cataloguing and classification had to be given serious attention. There were three reasons for this:

(1) During the war there had been time only to attend to urgent matters. Classification and arrangement had not kept pace with new publication and the increased demands of those by whom the Library and Information Department are used.

(2) The spate of publications which had not been obtainable during the war or which had then not been freely available had to be assimilated.

(3) In 1938 the libraries of The Iron and Steel Institute and The Institute of Metals had been joined. The new accretions had scarcely been absorbed when war broke out, while, after its conclusion, it was clear that the Library would have to deal with the literature on non-ferrous metals as well as that on iron and steel.

The time was clearly ripe for adopting a comprehensive system of classification.

During a visit to Germany soon after the end of the war, my attention was drawn to the merits of the Universal Decimal Classification by Dr. H. Dickmann. I gladly take this opportunity of acknowledging our debt to Dr. Dickmann and to the Verein deutscher Eisenhüttenleute.

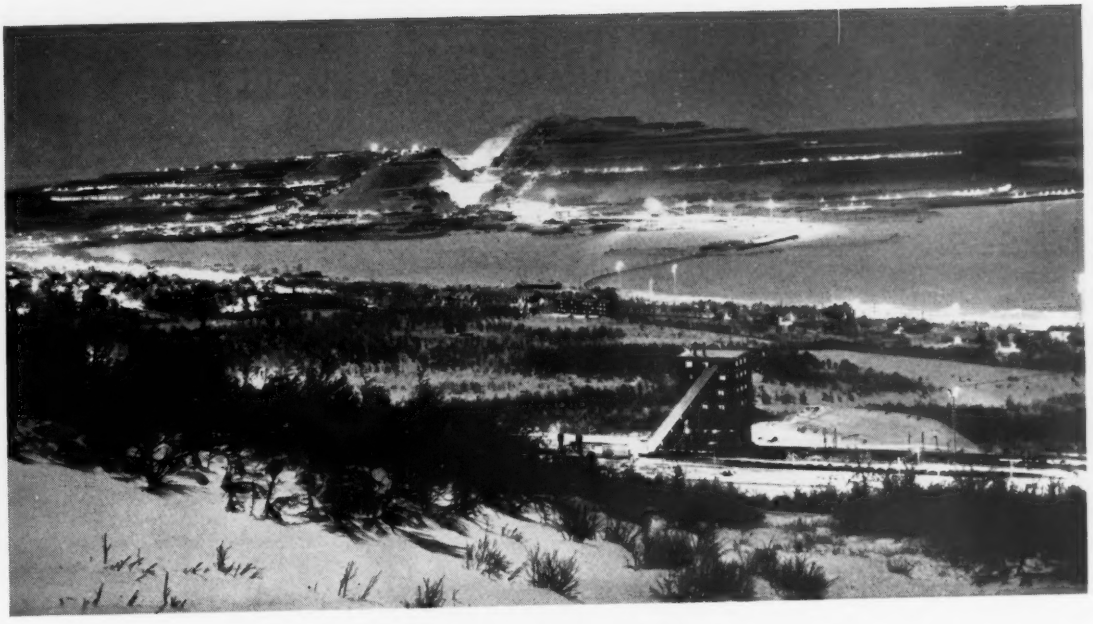
Soon afterwards, Mr. A. Post and Dr. M. A. Vernon, who was at that time our Information Officer, made an intensive study of the system in Germany. Their report corroborated the impression previously formed. There was little doubt that we should have to change the alphabetical system on which we had been working; if we did so, there seemed much to be said for adopting the system which at least claimed to be universal and for which there had been built up an international machinery for revision and adaptation by mutual agreement between prominent users; above all, the system worked and it seemed likely that it could be made to work with substantially less staff and at substantially less cost than in Germany by omitting unnecessary refinements. The Council approved of the proposals.

Experience in recent years has confirmed that this decision was right. Time does not permit me to go into details; they are given in the paper. One author, Mr. J. P. Saville, unfortunately could not come with us to Sweden. As Information Officer of The Institute, he is responsible for operating the system. He has established himself as one of the chief authorities on the classification of technical literature. I, for one, am grateful to him—and also to the Council, for the facilities they have made available to Mr. Saville for attending the meetings and congresses in which the details of these things are hammered out in discussion and hard bargaining. I must also record our indebtedness to the British Standards Institution and to their officer, Mr. G. A. Lloyd.

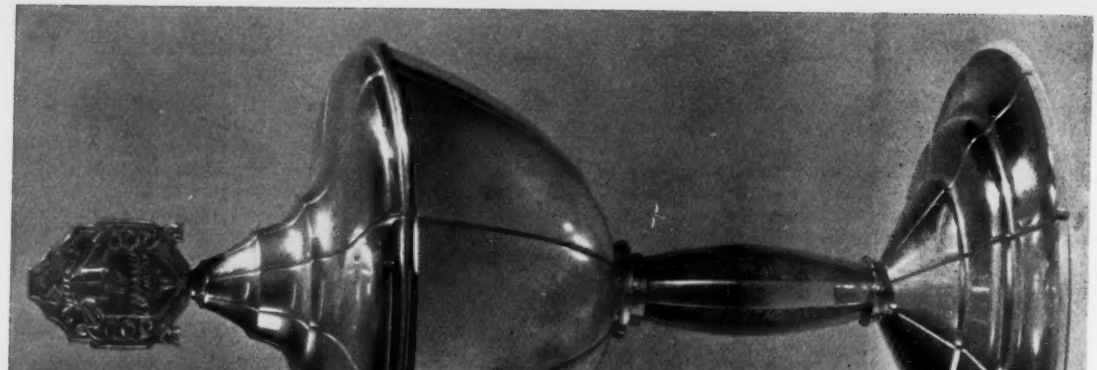
The other co-author is here to speak for himself and his colleague. Mr. E. Öhman, in addition to many other qualifications, is one of the leading experts in the world on the classification of technical literature for use by the iron and steel industry and in the operation of the U.D.C., but his modesty is so disarming that we are sometimes in danger of forgetting his distinction in this and in other fields.

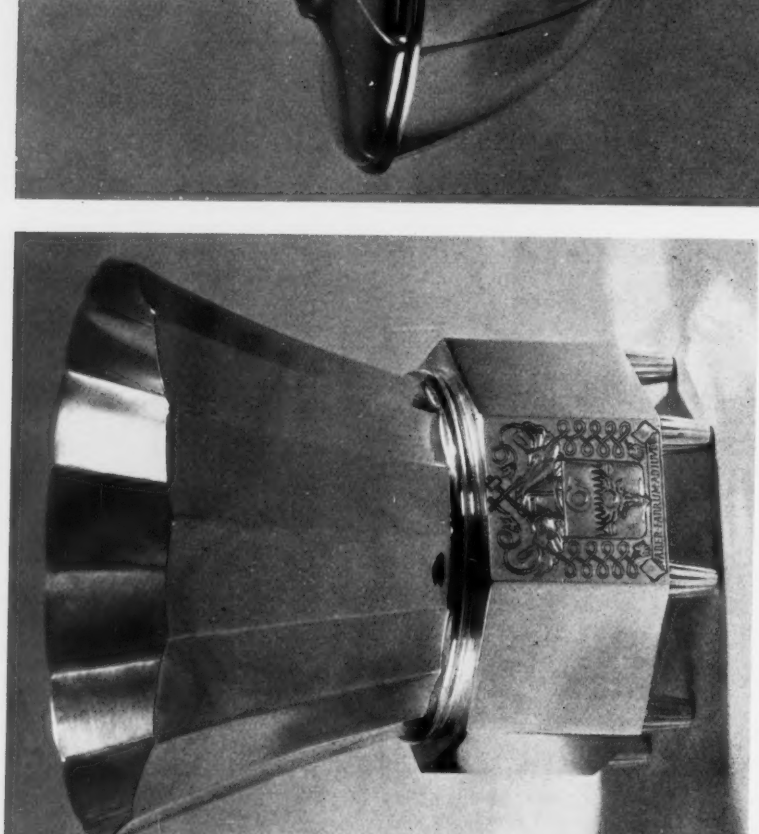
Mr. **Einar Öhman** (Jernkontoret): The amount of technical information published in books and periodicals and as more or less restricted technical reports increases rapidly every year, and nobody has the time to read more than a very small fraction of what may be useful to him now or at a later stage. In this situation it becomes increasingly important to collect, to abstract, and to publish information in such a way that continuous surveys of different technical fields are obtained. But it is no less important that the information should be filed in such a way that it is immediately available when needed. That means *classification.*

There are many types of classification system, and they may conveniently be divided into two groups: *special* and *universal.* An investigator working in a narrow field may use a special system—he may even



General view of Kiruna, Sweden

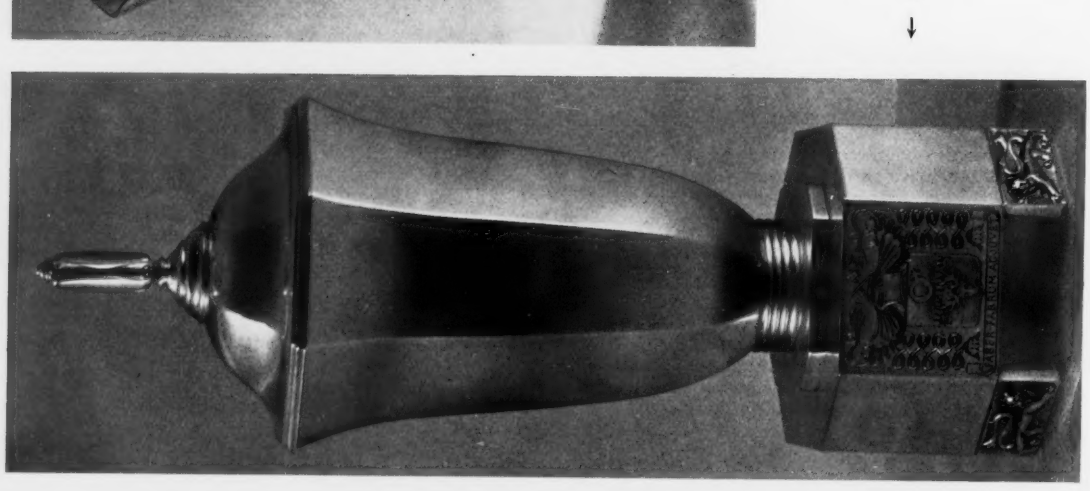




Presented to Mr. and Mrs. Sten Grönblom

← Presented to Mr. and Mrs. Berndt Grönblom

Presented to Mr. and Mrs. G. Frisell →



invent one himself—and this system may be developed to any degree of detail, as required by the purpose at hand. Thus a metallurgist interested in ferrous or non-ferrous alloys, their properties, treatment, and application may find the system recently developed by the American Society for Metals in collaboration with the Special Libraries Association extremely valuable. But for the information departments of The Iron and Steel Institute, Jernkontoret, or Verein deutscher Eisenhüttenleute, such a system is inadequate, and in my opinion it is also inadequate for the special libraries and information departments of the various metallurgical industries.

The variety of information required by the officials in industry, whether on the administrative, commercial, or technical sides, is so surprisingly large that only a universal classification system—a system comprising all human knowledge—will suffice. In addition to all technical fields from metallurgy in the strict sense to electrical engineering, building, and photography we have to cater for legislative, economic, and social questions, to mention only a few examples. And among the universal systems it is only the Universal Decimal Classification (U.D.C.) that can be seriously contemplated. It is worked out in sufficient detail, it is widely used in a great many countries, and it is being continuously revised by experts under the auspices of the International Federation of Documentation in The Hague.

Like everything devised by man the U.D.C. has its shortcomings. Experience in Sweden as in many other countries, however, shows that these are not too serious. Thus, as a result of the work of the Swedish Society for Technical Documentation the system is now being successfully employed by some two hundred special libraries in Sweden, and we have been able to introduce a fairly consistent and uniform classification practice. Practically all technical and economic journals in Sweden publish the U.D.C. numbers of all their articles and a card index is published, which constitutes a fairly complete bibliography of the Swedish technical and economic literature and a selective index of the world literature on mining, metallurgy, foundry technique, machining, building, and some other fields. The use of a common classification system has made it possible to a considerable extent to avoid duplication of work.

That this can be done also on an international level has been shown by the International Council for Building Documentation. Under their auspices classified abstracts are now being prepared in a number of countries of all building literature published within the country, and the abstracts are being exchanged between the participating countries. One of the main difficulties is that the usefulness of the co-operation will be considerably reduced if the classification practice is not the same in all countries. To ensure a consistent classification the Council has issued selected schedules with instructions.

By co-operation between our two institutions and the Verein deutscher Eisenhüttenleute a similar special U.D.C. edition for the metallurgical industries is now being prepared. Certain work on the revision of the system, in which both the Institute and Jernkontoret take active parts, will have to be concluded before the schedules can be published. It will therefore take some time before they are available, but it is our sincere hope that, when ready, it will prove a useful tool for co-operation in the field of metallurgical documentation and that it will considerably facilitate the use of the U.D.C. at special libraries and information centres in many countries.

The initiator of this special U.D.C. edition and the main author of the present paper is Mr. J. P. Saville, the Information Officer of the Institute. Unfortunately he is unable to attend this meeting and it has become my duty to present the paper. In concluding this presentation I should like to express my gratitude to the Council of the Institute for allowing me to demonstrate that in the field of documentation an active co-operation is in progress between The Iron and Steel Institute and Jernkontoret for the benefit of our respective members and for the metallurgical industry at large.

PRESENTATIONS

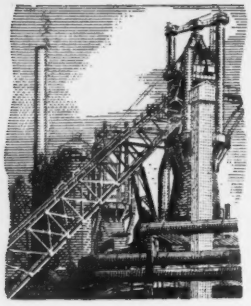
At the request of the Council, the President, The Hon. R. G. Lyttelton, flew to Sweden and Finland in order personally to present English silver cups to Mr. and Mrs. Gösta Frisell, and to Mr. and Mrs. Berndt Grönblom and Mr. and Mrs. Sten Grönblom. The presentation to Mr. Frisell, who had been responsible for organizing the meeting in Sweden on behalf of Jernkontoret, and to Mrs. Frisell, was from the Institute; those to Mr. and Mrs. B. Grönblom and to Mr. and Mrs. S. Grönblom had been subscribed for by the Members who visited Finland as guests of Mr. Berndt Grönblom and Oy Vuoksenniska AB. Mr. Lyttelton stayed at the British Embassies and the presentations were made at dinner parties given for the purpose by the British Ambassadors and Mrs. M. J. Creswell and Lady Hankey in Helsingfors and Stockholm on 26th and 29th January, 1955, respectively.

Illustrations of the three cups appear on the plate facing this page. They were made by hand in sterling silver to the design of Mr. C. L. Bruno of R. G. Hennell and Sons., Ltd., of London.

The cup presented to Mr. Berndt Grönblom has embossed on each of its feet the Lion of England, while that for Mr. Frisell bears English roses upon its stem. There was, unfortunately, no place for symbols of this sort on the bowl made for Mr. Sten Grönblom.

Upon each piece is engraved the coat of arms of The Iron and Steel Institute, together with its motto, "*Faber fabrum adjuvet.*"

The hall-marks upon the cups have the following significance. The 'lion passant' means that the silver of which the piece is made has been tested and found to be of sterling standard; the 'Leopard's head' shows that the test was made at the Assay Office in the Hall of the Worshipful Company of Goldsmiths in the City of London; the letter 'T' is the 'date-letter' in use at that office for the year May, 1954–May, 1955; the initials 'R.G.H.' are the mark of the makers as registered at the Goldsmiths' Hall.



PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research

A Short History of Iron and Steel Making in Finland

By Nils Hellén

SYNOPSIS

A brief account is given of the development of the iron and steel industry in Finland, its early dependence on Swedish ores, and the later development of the basic open-hearth and, more recently, electric furnaces. 1084

THE HISTORY of the modest, yet ancient, iron industry of Finland is largely one of trial and error, of unfulfilled hopes and deficient resources, natural as well as economic.

The beginning of ironmaking in Finland is hidden in the obscurity of prehistoric times. Since Finland formed part of the Kingdom of Sweden until 1809, the development of Finnish ironmaking followed—slowly and on an infinitely smaller scale—the same lines as in Sweden proper, which have been described by Fornander.*

In Finland, as in Sweden, bog ore was the first raw material used. Such ore is found in the lakes of Central and Eastern Finland and in the bogs on the Carelian isthmus. In mediaeval times this ore was reduced in shallow ground pits, but later small furnaces were used, the blast being provided by bellows.

In the sixteenth century, when the blast-furnace process had already been in use in Sweden for a century, the existence of rock ore deposits was investigated in Finland, since that country possessed a ready supply of the only fuel then used for ironmaking—charcoal—and a relative abundance of water power. The deposits, however, turned out to be insignificant. The first iron mine, Ojamo in the south-west of Finland, was opened in 1542. Close to this mine the first blast-furnace was built in 1618, and shortly afterwards the first tilt-hammer was added. They were soon followed by many others, all unpretentious and many of them bringing economic ruin to their owners. The scant native ore resources did not permit profitable ironmaking on an industrial scale. Very soon almost all the Finnish iron works, whose main product was wrought iron, were exclusively using iron ore imported from Sweden.

The many wars with Russia in the eighteenth century again and again laid waste the industry, and the repeated efforts of the State to support it by means of subsidies and exemption from taxes could not prevent it from languishing. This precarious situation was aggravated when Sweden had to cede Finland to Russia in 1809. Since the accustomed supply of Swedish ore was threatened, no native iron mines being in operation at that time, the twenty-eight iron works of the new-born autonomous Grand-Duchy faced a gloomy situation. Energetic efforts were made to revive the production of the abandoned mines, and ore prospecting was carried on vigorously with the support of the State. The results were not gratifying; during the whole nineteenth century a total of 165,000 metric tons of native rock ore of poor quality were made available. Treaties with Sweden secured, however, the indispensable minimum of imported ore, and the development of ironmaking and manufacture gradually quickened pace. The introduction of the puddling process in 1853 and of the rolling technique provided a great stimulus, and the exploitation of bog ore was multiplied, reaching a maximum in 1897 of over 75,000 metric tons.

* S. Fornander, *J. Iron Steel Inst.*, 1954, vol. 177, May, pp. 1–12.

Manuscript received 12th November, 1954.

Mr. Hellén is with Oy Vuoksenniska AB, Imatra, Finland.

Table I

FINNISH IRON AND STEEL PRODUCTION 1931–1953

All productions in metric tons

Year	Pig Iron			Raw Steel Output	Import of Billets	Rolled Steel		
	Output	Imports	Exports			Output	Imports	Exports
1931	5007	13,713	...	17,924	3000 (approx.)	18,961	69,911	...
1935	5605	41,392	...	44,861	26,656	56,766	158,923	290
1938	26,000 (approx.)	29,000 (approx.)	11,000 (approx.)	76,546	18,113	97,018	166,676	72
1940	26,843	13,269	41	77,033	4348	69,303	99,010	13
1945	35,017	701	3982	86,006	1510	58,789	43,971	632
1951	101,522	7518	13,663	130,495	33,806	127,043	301,133	6688
1953	79,847	6446	3074	147,851	17,229	119,406	157,211	6416
1954	74,610	50,403	1047	177,103	52,779	150,415	370,000	1639

On the other hand, those of the old wrought-iron producers who were not able to establish puddling works and rolling mills had to limit or discontinue their activities. Some found their salvation by transforming their production into manufactured articles, and several of the ancient ironworks gave their names to factories of various kinds, which still exist. Evolution took a further step forward when in 1879 the first open-hearth furnace was built at Dalsbruk; this was soon followed by another at Wärtsilä. As the native ores were unsuitable for the production of pig iron for the open-hearth, the mining of rock ore ceased and the use of bog ore sank to a fraction of what it had been. Instead, Swedish ores were imported and the use of scrap was introduced.

The home market being very small, the ironmaking of Finland was wholly dependent on the export of its surplus to Russia. This could be done profitably so long as Russia allowed Finnish iron to be imported free of duty. But at the end of the last century the Russian Empire entered upon a policy of high tariffs and the Finnish iron production consequently dwindled. Gradually, however, the expanding home market formed by the rapidly growing engineering industry was able to absorb a greater output of iron and steel. When Finland became independent in 1917, it possessed an unbroken though slender tradition of native ironmaking.

The making of pig iron with charcoal had become uneconomic by then and the reserves of wood could be used more profitably for the production of pulp. The last charcoal blast-furnace, at Dalsbruk, was closed down in 1928. In 1916, production of electric pig iron from scrap had been started at Vuoksenniska, and in 1937 an electric low-shaft furnace (annual capacity 30,000 metric tons) was put into operation at Imatra, using as its raw material pyrites residue from the Outokumpu copper mine. In 1943 a coke blast-furnace was built at Åbo with an annual capacity of 80,000 tons.

The older techniques of steelmaking were gradually abandoned—the Lancashire process in 1908 and puddling in 1917—and so the open-hearth process (from 1928 exclusively the basic O.H.) was for some time unchallenged in Finland. In 1937, however, electric steelmaking was introduced at a newly built plant at Imatra, and today by far the greatest part of the steelmaking in Finland is effected in electric furnaces.

At present Finland possesses one coke blast-furnace (Åbo), one electric pig-iron furnace on an ore basis (Imatra), both of which are owned by Oy Vuoksenniska AB, one electric plant for the production of synthetic pig iron from scrap (Uusi Wärtsilä, owned by the Wärtsilä Concern), three open-hearth furnaces (Åminnefors and Inha, owned by Oy Fiskars AB, and Dalsbruk, belonging to the Wärtsilä Concern), and one electric steelworks (Imatra, Oy Vuoksenniska AB). Three large steel foundries also exist in connection with mechanical workshops.

Of the three iron and/or steel producing companies mentioned, Fiskars in south-western Finland was founded as early as in 1649. Today Fiskars controls a considerable number of affiliated firms, the group producing in addition to raw iron and steel a great variety of manufactured steel articles. Dalsbruk, not far from Åbo, is not much younger, its year of foundation being 1686. It was fused into the Wärtsilä Concern in 1938. The latter derives its name from a locality, ceded to the Soviet Union after the last war, in Carelia, where in 1834 a blast-furnace was built. The concern comprises a number of workshops and the two biggest shipbuilding yards of the country. The Vuoksenniska Company dates from 1915, when a ferro-alloy plant was started at Vuoksenniska, near Imatra, in Carelia. At present the firm is Finland's biggest producer of iron and steel.

The development in recent years of the production of pig iron, raw steel (including steel castings), and rolled products, as well as some import figures, are given in Table I. These figures testify that, in spite of setbacks due to wars and periods of depression, the iron and steel industry of Finland in recent years has considerably increased its output. It has been able to meet the demands laid upon it by the wars and by the payment to the Soviet Union of reparations for war damages. In times of isolation it also guarantees a minimum of self-support in an important field. Furthermore, in many of the unsuccessful enterprises of the past lay germs for the later industrialization of the country—for its internationally important timber, pulp, and paper industries or for its steadily growing engineering industry.

The Strain-Ageing of Pure Iron

AGEING OF PURE IRON AFTER TEMPER-ROLLING AND TENSILE-STRAINING

By B. Jones, D.Sc., and R. A. Owen-Barnett, M.Sc.

SYNOPSIS

The ageing characteristics of two samples of pure iron containing less than 0·004% of carbon and 0·002% of nitrogen have been investigated after temper-rolling and after tensile-straining. After these treatments, the irons showed an appreciable degree of strain ageing that was almost equivalent to that of open-hearth mild steel. After temper-rolling, the rate of ageing of pure iron is more rapid than in commercial steels, and was found to be complete within one month; it was then equivalent to the strain ageing that occurred on heating to 75–250°C. In contrast, ageing of mild steel progressively develops over a period of years. The rapid ageing of pure iron has been explained by the ease of migration of carbon and nitrogen atoms in the α-iron lattice. Strain ageing of iron was eliminated by annealing in moist hydrogen, which reduced the carbon and nitrogen contents to almost zero values. 1047

A RESEARCH programme on the ageing of mild-steel strip after temper-rolling and after tensile-straining entailed a comparison of the ageing characteristics of iron of high purity. A sample of hard-rolled pure iron *AHP*6, 18 in. × 3 in. × 0·15 in., was obtained from B.I.S.R.A. and subjected to ageing tests. The results of preliminary tests after temper-rolling have been included in a recent paper on the strain ageing of mild steel[1] and, in view of the results of further tests, another sample of pure iron *AHP*10, 4 ft. 4 in. × 3 in. × 0·118 in., was tested; this iron was received in the hot-rolled condition.

PURE IRON *AHP*6

For temper-rolling tests the thickness of the sample was reduced to approximately 0·05 in. Before cold-rolling, the iron was annealed to impart an even grain size. Sample pieces of the original hard-rolled material were annealed *in vacuo* at temperatures from 700° to 930°C., and the microstructures obtained at these various temperatures are illustrated in Fig. 4. Although mild steel recrystallizes at approximately 600°C. after heavy cold-reduction, it was found that the pure iron did not completely recrystallize at temperatures below 900°C. The hard-rolled iron was annealed, therefore, for 2 hr. *in vacuo* at 930°C. and was cold-reduced 60% in a single-stand 4-high mill with $8\frac{3}{4}$-in. dia. work rolls. The strip was cut into 6-in. lengths, machined to standard tensile test pieces (B.S.S. 18, test piece *A*, 2-in. gauge length), and again annealed *in vacuo* at 930°C. to obtain a uniform grain structure before the straining operations.

Some of the annealed test pieces were temper-rolled 2·4% and the remainder were strained to 6% elongation in a tensile testing machine. After temper-rolling, the iron was tested within 15 min. and after 1 month. Artificial ageing tests were carried out at 75–250°C. After tensile-straining, the iron was tested immediately and after heating to 100–250°C. The results are given in Table I. Figure 1 illustrates the autographic stress/strain curves of the iron after these various ageing treatments.

The yield stress given in Table I corresponds to the lower yield point, which was indicated by the horizontal portion of the curve. When the curve oscillated gradually between two limits of stress, the yield stress quoted is the average of the two limits. In the freshly temper-rolled steels, the yield stress given is the stress at which the load/elongation curve departs from a straight line.

Temper-rolling removed the yield point, and in the freshly rolled condition the yield stress was about 8% lower than in the annealed iron. The hardness increased from 66 to 72 D.P.N., but there was little change in the U.T.S. and the percentage elongation. On ageing at room temperature, a yield point returned within 1 month with a fairly appreciable increase in yield strength, U.T.S., and hardness, and with a reduced ductility. Artificial ageing tests were made at 75°C., at which temperature the residual stresses in steel are not appreciably relieved, and at 100–250°C., which progressively relieve these stresses. The results after temper-rolling and ageing at 20°C. for 1 month are similar to those after artificial ageing at 75–250°C., which show that ageing was complete in this short period of time and that the rate of ageing of pure iron is more rapid than in commercial steels, the physical properties of which change continuously over a period of 1–3 years.[1]

Table I and Fig. 1 show that the ageing of the iron is also fairly appreciable after tensile-straining and heating to 100–250°C., as shown by the magnitude of the yield-point elongation and an ageing index above 27%. These effects are greater than those

Manuscript received on 18th August, 1954.

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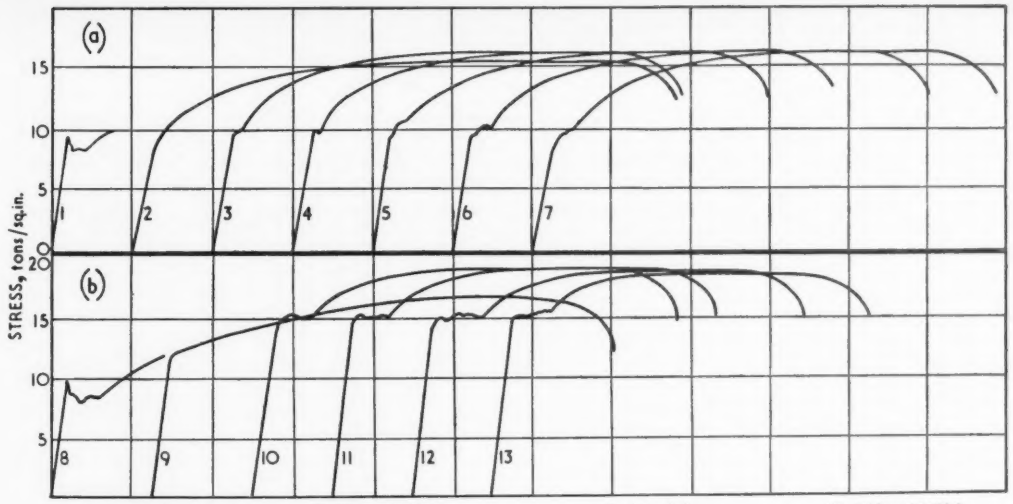


1. Annealed
2. Temper-rolled
3. 1 month at 20° C.
4. 24 hr. at 75° C.
5. 24 hr. at 100° C.
6. 3 hr. at 200° C.
7. 1 hr. at 250° C.

(*a*) Temper-rolled 2·4% reduction and aged

8. Annealed
9. Strained 6%
10. 2 hr. at 100° C.
11. 24 hr. at 100° C.
12. 3 hr. at 200° C.
13. 1 hr. at 250° C.

(*b*) Tensile-strained 6% elongation and aged

Fig. 1—Stress/strain curves of pure iron *AHP*6

found in aluminium-killed steel and approach those of open-hearth mild steel.

PURE IRON *AHP*10

The hot-rolled material was cold-reduced 60% and machined to standard tensile test pieces as before. These were annealed *in vacuo* for 2 hr. at 930°C. Some of the annealed pieces were temper-rolled 2% ; the remainder were strained to 3% elongation, which was sufficient to remove the yield point, as indicated by the tests on pure iron *AHP*6. The specimens were subjected to the same ageing treatments as before. The results are given in Table II, and the stress/strain curves obtained are illustrated in Fig. 2.

Allowing for the somewhat smaller amount of cold work and the differences in carbon and nitrogen contents, the strain ageing of this iron follows the same trend as that of pure iron *AHP*6.

Table I

AGEING OF PURE IRON *AHP*6

C, 0·0021% ; Mn, 0·005% ; Si, 0·001% ; Al, 0·0029% ; O_2, 0·0097% ; N_2, 0·0011%

(*a*) After Temper-Rolling 2·4%

Ageing Treatment	Yield Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, % on 2 in.	Yield-Stress/U.T.S. Ratio, %	Hardness, D.P.N.
Annealed	8·3	15·6	46	53·2	66
As temper-rolled	7·3	15·4	46	47·4	72
1 month at 20°C.	10·0	16·0	39	62·5	80
24 hr. at 75°C.	10·0	16·1	40	62·2	80
24 hr. at 100°C.	10·1	16·0	39	63·1	78
3 hr. at 200°C.	10·1	16·0	40	63·1	78
1 hr. at 250°C.	9·8	15·9	39	61·7	79

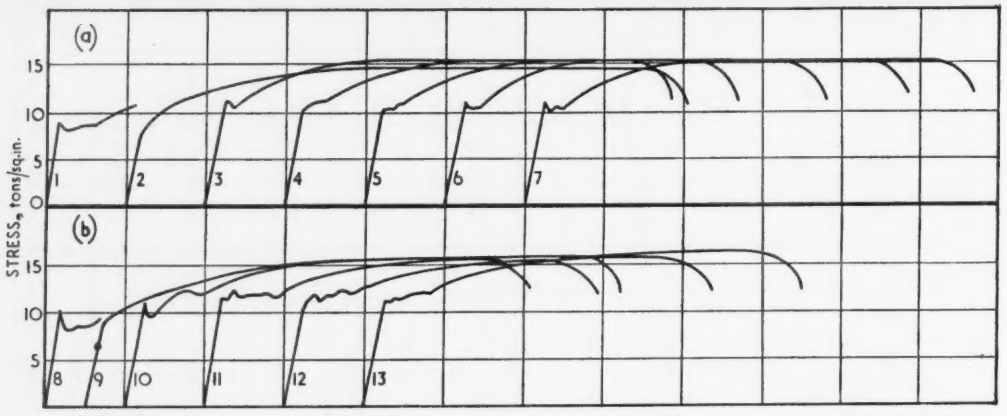
(*b*) After 6% Tensile-Straining

Ageing Treatment	Yield Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, % on 2 in.	Yield-Stress/U.T.S. Ratio, %	Ageing Index*
Annealed	8·3	...	...	...	...
As strained	12·2	16·7	39	73·0	...
2 hr. at 100°C.	15·3	19·2	34	79·6	25·4
24 hr. at 100°C.	15·2	19·2	33	79·1	24·6
3 hr. at 200°C.	15·2	19·1	32	79·5	24·6
1 hr. at 250°C.	15·4	19·0	32	81·1	26·2

* Percentage increase of yield stress.

DISCUSSION OF RESULTS

It has been shown that the rate of natural ageing of pure iron after temper-rolling is more rapid than in commercial low-carbon steels. The solubility of carbon in pure iron under equilibrium conditions is of the order of 10^{-7}%[2] and that of nitrogen 0·0002%.[3] It is likely, therefore, that the pure irons are supersaturated with respect to carbon and to nitrogen. Manganese lowers the solubility of nitrogen and probably that of carbon in ferrite,[4, 5] so that amounts of carbon and nitrogen retained in solid solution in mild steel are less than in pure iron. Fast and Dijkstra[6] showed by internal friction measurements that manganese delays the quench ageing of iron by retarding the precipitation of nitrogen retained in solid solution, owing to the great affinity of manganese and nitrogen atoms. It was stated that manganese had little effect on the precipitation of carbon from solid solution. Commercial steels also contain constituent elements and impurities, which may restrict the rate of migration of carbon and nitrogen atoms. It would be expected, therefore, that nitrogen atoms would move more rapidly in pure iron after straining than in commercial steels. The rapid rate of ageing of the irons can be explained by the effects of the small amounts of carbon and nitrogen. In addition, the degree of ageing is almost equivalent to that of open-hearth mild steel.



1. Annealed
2. Temper-rolled
3. 1 month at 20° C.
4. 24 hr. at 75° C.
5. 24 hr. at 100° C.
6. 3 hr. at 200° C.
7. 1 hr. at 250° C.

(*a*) Temper-rolled 2% reduction and aged

8. Annealed
9. Strained 3%
10. 2 hr. at 100° C.
11. 24 hr. at 100° C.
12. 3 hr. at 200° C.
13. 1 hr. at 250° C.

(*b*) Tensile-strained 3% elongation and aged

Fig. 2—Stress/strain curves of pure iron *AHP*10

There are fewer restrictions to the migration of carbon and nitrogen atoms in the crystal lattice of pure iron during ageing, owing to the relatively small number of stranger atoms in the lattice. The vacant sites at dislocations, etc., caused by the cold work, become rapidly occupied by the available carbon and nitrogen atoms, although residual stresses are present. In other words, residual stresses have less influence on the migration of carbon and nitrogen atoms than in commercial steels, and consequently there is a close agreement between natural and artificial ageing of pure iron after temper-rolling.

Table II

AGEING OF PURE IRON *AHP*10

C, 0·0036%; Mn, < 0·005%; Si, 0·001%; Al, 0·001%; O_2, 0·0024%; N_2, 0·0016%

(*a*) After Temper-Rolling 2·0%

Ageing Treatment	Yield Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, % on 2 in.	Yield-Stress/U.T.S. Ratio, %	Hardness, D.P.N.
Annealed	8·0	15·1	47	53·0	63
As temper-rolled	7·3	15·0	47	48·6	78
1 month at 20°C.	11·3	16·1	39	70·2	88
24 hr. at 75°C.	11·2	16·0	38	70·0	86
24 hr. at 100°C.	10·8	16·1	39	67·1	87
3 hr. at 200°C.	10·9	16·2	39	67·2	88
1 hr. at 250°C.	10·9	16·3	38	66·9	86

(*b*) After 3% Tensile-Straining

Ageing Treatment	Yield Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, % on 2 in.	Yield-Stress/U.T.S. Ratio, %	Ageing Index*
Annealed	8·1	...	...	...	...
As strained	9·0	15·5	43	58·0	...
2 hr. at 100°C.	11·6	16·0	34	68·1	28·9
24 hr. at 100°C.	11·7	16·4	32	71·2	30·0
3 hr. at 200°C.	11·8	16·2	33	72·8	31·1
1 hr. at 250°C.	11·7	16·5	34	70·9	30·0

* Percentage increase of yield stress.

Iron *AHP*10 aged more than *AHP*6 owing to the greater amounts of carbon and nitrogen available for migration.

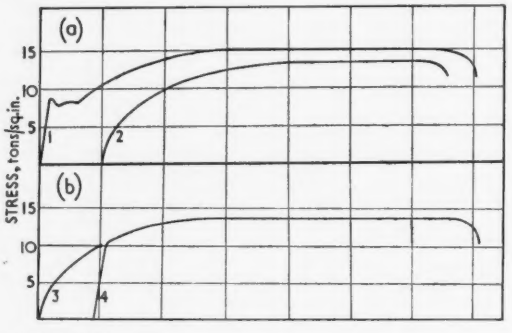
The results after tensile-straining show the pronounced ageing effects that are obtained in iron with very low carbon and nitrogen contents.

HYDROGEN TREATMENT OF PURE IRON *AHP*10

As the small amounts of carbon and nitrogen present in the samples of pure iron are responsible for strain ageing, tests were carried out to eliminate these elements in iron *AHP*10 by an annealing treatment in moist hydrogen.

Two tensile test pieces were annealed at 780°C. for 16 hr. in hydrogen saturated with moisture at 65°C. One piece was tested in the annealed condition, and the other was strained to 6% elongation and aged for 1 hr. at 250°C.

The stress/strain curves of the iron annealed *in vacuo* and subsequently annealed in moist hydrogen are shown in Fig. 3*a*. Figure 3*b* illustrates the elimination of strain-ageing in the iron after hydrogen treatment.

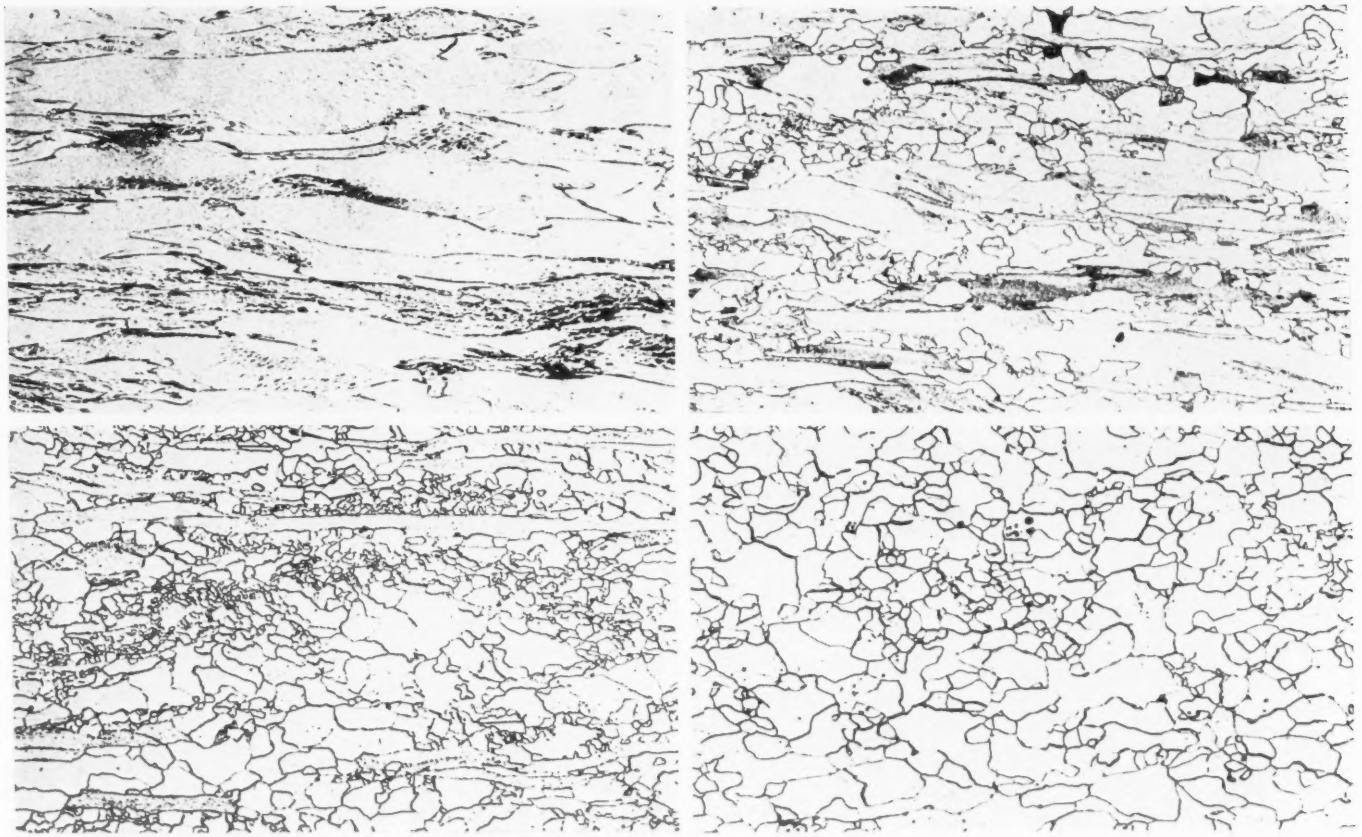


1. Annealed *in vacuo*
2. „ „ „ + annealing in moist hydrogen for 16 hr. at 780° C.
3. Annealed in moist hydrogen, strained 6% elongation
4. As curve 3 + heating for 1 hr. at 250° C. (absence of strain ageing)

Fig. 3—Pure iron *AHP*10 : (*a*) Stress/strain curves, (*b*) strain-ageing test.

(a) As received, cold-reduced 70%. Hardness: 184 D.P.N.

(b) 2 hr. at 700° C. Hardness: 99 D.P.N.



(c) 2 hr. at 750° C. Hardness: 77 D.P.N.

(d) 2 hr. at 800° C. Hardness: 72 D.P.N.

Fig. 4—Annealing of cold-reduced pure iron *AHP*6 × 100

[*Jones and Owen-Barnett*
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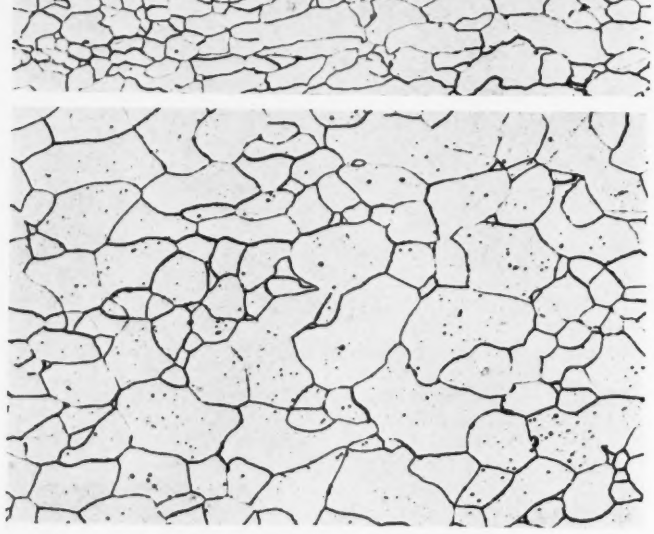
(e) 2 hr. at 850° C. Hardness: 70 D.P.N.

(f) 2 hr. at 900° C. Hardness: 67 D.P.N.



(g) 2 hr. at 930° C. Hardness: 66 D.P.N.

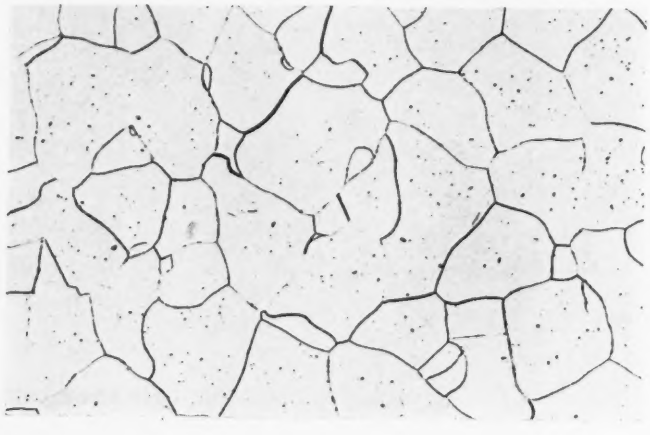


Fig. 4 (contd.)—Annealing of cold-reduced pure iron *AHP6* × 100

Annealing in hydrogen completely removes the yield point in a stress/strain curve by reducing the carbon and nitrogen contents to negligible amounts. The yield strength after hydrogen treatment is of a very low value (approx. 2 tons/sq. in.). The percentage elongation on a 2-in. gauge length is, however, rather low for high-purity iron (37%). The tensile test piece did not show signs of 'necking' before fracture. A bend test showed that the material withstood a bend of less than 90° before fracture. The strength of the grain boundaries had evidently been impaired by the hydrogen treatment, possibly by removal of traces of grain-boundary carbide and its replacement with oxide films. This caused intercrystalline embrittlement, which was found on stressing the iron, such as in a bend test.

CONCLUSIONS

(1) Pure iron with a large grain size (approx. 0·18 mm.) and containing carbon and nitrogen of 0·002–0·004% and 0·001–0·002%, respectively, exhibits a well-defined yield point in an autographic stress/strain curve.

(2) A fairly appreciable amount of strain-ageing occurs after temper-rolling or tensile-straining.

(3) The rate of ageing of pure iron at room temperature after temper-rolling is considerably greater than with commercial low-carbon steels, the amount of ageing approaching that of open-hearth mild steel.

(4) In contrast with commercial mild steel, artificial ageing treatments of temper-rolled pure iron at 75–250°C. give results that are similar to those after ageing for 1 month at 20°C. This is due to the ease of migration of the carbon and nitrogen atoms in a crystal lattice relatively free from atoms of manganese, etc., which tend to restrict their movement. Residual stresses induced by rolling do not appreciably retard the rate of ageing.

(5) Annealing in moist hydrogen eliminates the yield point and strain-ageing, as carbon and nitrogen are reduced to extremely low values.

Acknowledgments

The samples of pure iron were kindly supplied by the British Iron and Steel Research Association. The authors are grateful to Mr. G. H. Latham, J.P., LL.D., Chairman of the Whitehead Iron and Steel Co., Ltd., for his interest in the work and for permission to publish the paper.

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Metallographic Polishing of Cast Iron

A SIMPLIFIED METHOD USING DIAMOND ABRASIVES

By L. E. Samuels, B.Met.E.

SYNOPSIS

The method, which is intended primarily for the more difficult types of specimen containing coarse graphite, is a modification of a general method of metallographic polishing based on the use of diamond abrasives. The essential change is in the use of a napless cloth for the diamond abrasive pad. Results at least the equal of the best previously published methods can be obtained in a relatively short polishing time and with the minimum of skill. 1042

THE STANDARD for the metallography of cast iron containing free graphite has been set for many years by Morrogh and his co-workers of the British Cast Iron Research Association ; the recent publication[1] of a selection of representative micrographs is proof of the high standard attained. Morrogh has described his polishing technique,[2] which owes its success to the correct application of repeated polishing and etching treatments at the finish-polishing stage. With the more difficult types of specimen (*i.e.*, those containing very coarse graphite), however, the repeated polishing and etching process is very laborious, some specimens requiring as many as 30 cycles of treatment. Furthermore, it seems that the process requires some degree of personal skill ; the author has never been able to attain the standard reached by Morrogh.

The author has recently developed an improved method of routine metallographic polishing based on the economical use of diamond abrasives.[3] Since it is well known that the use of this abrasive greatly

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facilitates the retention of non-metallic inclusions, and in view of the report by Woodside and Blackett[4] that excellent retention of flake graphite was achieved by a similar method of polishing, it seemed desirable to determine whether the preparation of cast-iron specimens could be simplified by these newer methods. Trials were therefore carried out on a wide range of specimens, and it was confirmed that good results could be obtained by the standard polishing method previously described with most commercial grey cast irons, in which the graphite flakes were relatively fine.[5] Completely satisfactory results could not be obtained, however, with irons containing coarse flake graphite, spheroidal graphite, or, more particularly, temper carbon nodules of the type present in blackheart malleable irons. A modified method, the principles of which are described in the present paper, has therefore been developed for these more difficult types of cast-iron specimen.

PRINCIPLES OF MODIFIED METHOD

As pointed out by Morrogh,[2] the preliminary abrasion stages play a critical part in the retention of graphite, since only if good retention is achieved at this stage can there be any hope of obtaining a satisfactory final polish. Particular attention has been given to this aspect in the present method, in that the aim has been to obtain almost complete retention of graphite at the end of the preliminary abrasion stages.

In the author's standard method of polishing,[3] abrasion is first carried out on a series of waterproof silicon-carbide papers lubricated with flowing water, which are followed by a special cast wax-alumina abrasive lap. This treatment is eminently suitable for cast-iron specimens. Firstly, the silicon-carbide papers themselves produce less damage in the graphite areas than the more usual emery papers. Secondly, the wax lap, in which the possibility of loose abrasive is reduced to the minimum, produces a relatively fine finish with maximum retention of graphite ; the surface produced on this lap is also very flat with well-preserved edges. Typical examples of the results obtained on specimens containing coarse flake graphite and temper carbon nodules, respectively, are shown in Figs. 1*a* and *b*. It will be noted that only a few small pits are present in the graphite areas. A comparison of Figs. 1*a* and *c*, and of Figs. 1*b* and *g*, also indicates that the graphite areas are free from serious distortion.

It has not been found possible, however, to maintain this degree of retention by a polishing stage in which diamond abrasive is used on a pad of napped cloth. Moderately satisfactory results can be achieved by using a cloth of short nap, heavy polishing pressures, and short polishing times, but such a process is difficult to control and the best results do not compare with those described later. The conclusion was reached that the desired results would be obtained only by the use of a napless cloth, as originally recommended by Vilella.[6] The silk cloth used by Vilella, however, has been found to be unsuitable for charging with the diamond-impregnated carrier paste, as the paste is rapidly pushed through the loose weave of the cloth and thereby lost.

Ideally, the cloth should have the minimum of nap and a close weave, so that the abrasive-impregnated paste is retained in the surface layers ; furthermore, it should not scratch the surface of the specimen. Of the many types of cloth tested by the author, none has been found to be completely satisfactory. Heavy cotton drill most nearly approached requirements, suffering only from the following limitations.

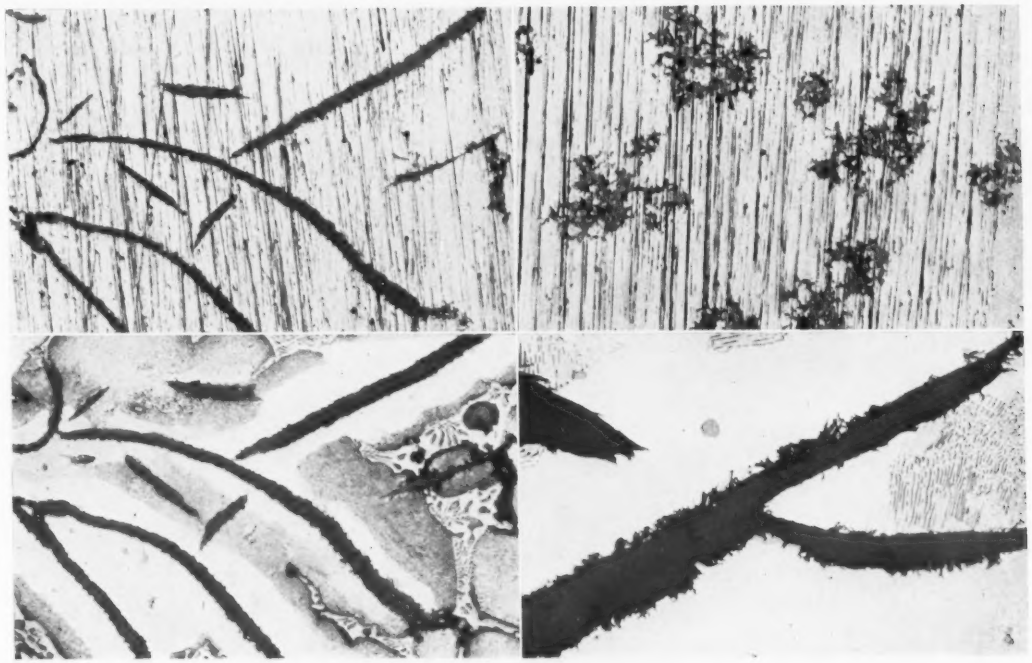
The impregnated paste works into the body of the cloth, gradually reducing the polishing rate. Furthermore, the cloth clogs rather rapidly with polishing debris, with consequent scratching. In practice, only one or two specimens can be satisfactorily prepared on each charging. In the interests of reasonable economy, the diamond abrasives should be restricted to a single stage, for which a (0–1)μ grade is the most suitable, and the pads should be used as follows. A small portion of paste, containing 2–3 mg. of abrasive, is spread over and rubbed into a 2–3-in. dia. area of the pad. A few drops of kerosene (light paraffin oil) are added, and the polishing is carried out by hand on this area. It is essential to use a lubricant such as kerosene with which the carrier paste is immiscible (the paste used is a water-base emulsion), otherwise the paste and abrasive are rapidly washed through the cloth. When the pad begins to scratch excessively, the cloth must be washed thoroughly and then dried before being recharged.

The pad requires no special precautions in use and shows no tendency to damage even the coarsest graphite areas. The treatment on the pad may therefore be continued until any preliminary damage to the graphite has been eliminated and the desired degree of retention has been achieved. Since the polishing rate of the pad is very high, the duration of this treatment rarely exceeds 5 min. The specimen may, with advantage, be etched several times during the treatment, but this is not essential. Representative examples of the three main types of graphite after polishing to this stage are shown in Figs. 1*c*, *e*, and *g*. The flake graphite of Fig. 1*c* is relatively coarse and is typical of the flake size for which the special technique is necessary. The retention of the individual spheroids of Fig. 1*e* is perhaps no better than that normally obtainable on napped cloths ; the improvement to be noted is that all the spheroids are completely retained. The best example, however, is the complete retention and the sharp appearance of the temper carbon nodules of Fig. 1*g* ; these are undoubtedly the most difficult of all the types of graphite to retain.

The surface produced on the drill-cloth pad inevitably is lightly scratched. When the pad is in a satisfactory condition, the scratches are never noticeable in micrographs of low magnification, even when the matrix is completely ferritic as in Fig. 1*g* ; they are, however, usually noticeable in flake or spheroidal graphite areas at high magnifications (say, × 500 or higher). A further finish-polishing treatment may then be desirable, for which a " Selvyt " cloth pad charged with a thick paste of calcined magnesium oxide is recommended ; this is one of the two finish-polishing methods recommended by Morrogh.[2]

(a) Coarse flake graphite; finished on alumina–wax lap × 100

(b) Temper carbon nodules; finished on alumina–wax lap × 100



(c) Coarse flake graphite; finished on diamond abrasive pad; nital etch × 100

(d) As (c), after finish-polishing on magnesium oxide pad; nital etch × 500

Fig. 1—Photomicrographs of cast-iron specimens

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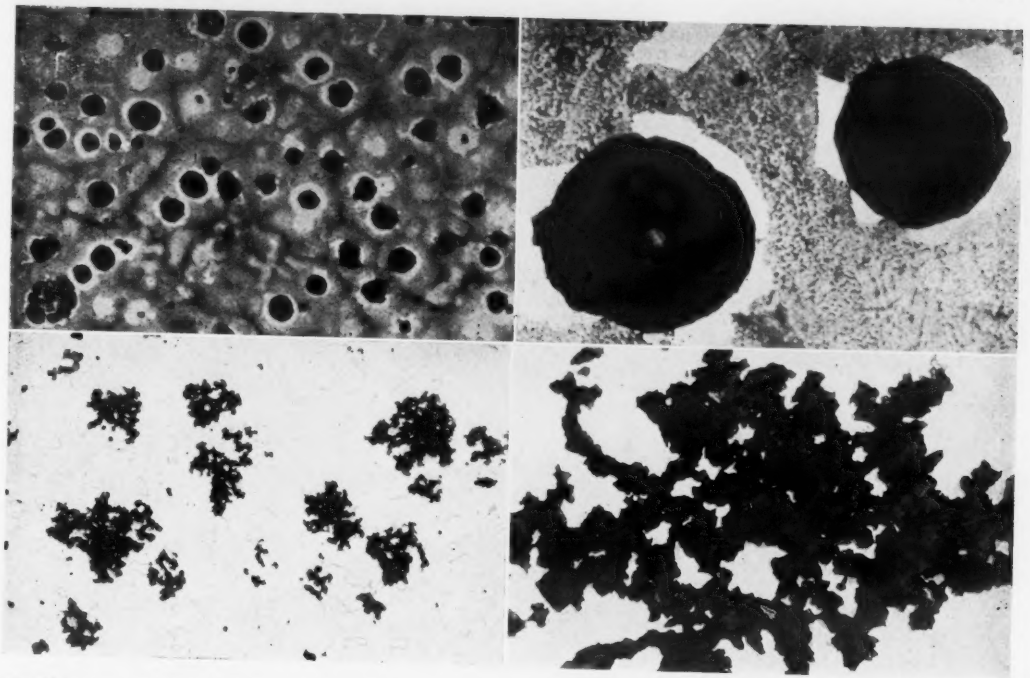

(e) Spheroidal graphite; finished on diamond abrasive pad; picral etch × 100

(f) As (e), after finish polishing on magnesium oxide pad; picral etch × 1000

(g) Temper carbon nodules; finished on diamond abrasive pad; nital etch × 100

(h) As (g) × 500

Fig. 1 (contd.)—Photomicrographs of cast-iron specimens

In the author's experience, however, such a treatment invariably results in some damage to the graphite no matter how carefully it is carried out. In the case of flake and spheroidal graphite, the damage is slight and many fields are usually of satisfactory appearance at high magnifications; these are the cases where finish-polishing may be used to advantage. On the other hand, temper carbon nodules are seriously damaged by even the briefest finish-polishing treatment, and it should not be used with these specimens. Fortunately, any scratches produced on the diamond abrasive pad are not noticeable in this form of graphite, and a finish-polishing treatment is hardly necessary (*see* Fig. 1*h*). It is not always appreciated that damage to the graphite is more noticeable at low than at high magnifications. For examination at low magnifications, a finish-polishing treatment has been found undesirable.

A finish-polishing treatment should therefore be used only when absolutely necessary and where previous experience has shown that excessive damage to the graphite areas does not occur. At best, the treatment must be brief (1–2 min. maximum duration) and can be expected only to remove fine scratches from the graphite areas. Consequently, it is of some importance to ensure that a polish free from major scratches is obtained on the diamond abrasive pad. These remarks apply, of course, only to finish-polishing pads used in the normal way, without special skill or care, and not to techniques of the type developed by Morrogh.[2]

The graphite areas after polishing on either the diamond abrasive or magnesium oxide pads are usually slightly stained. The best method of removing the stain without further damage is to wash the surface with soap and a piece of the material used for the finish-polishing pad. All the specimens shown in Fig. 1 were washed in this way. These micrographs were taken with a microscope fitted with a Foster-prism illuminator and do not show the slight polarization effects found with microscopes fitted with a plane-glass illuminator.[2, 7] The flat grey appearance of the graphite in these micrographs makes the presence of minor polishing blemishes or stains much more obvious.

Even with the best retention by the polishing methods described, approximately half the spheroids of spheroidal graphite irons contain a roughly hexagonal, lighter core (*see* Fig. 1*f*). In all such cases, the core was found to be virtually at the same level as the rim, and appeared to be merely a more highly reflecting area in the graphite. It was also found that these areas were the first to be damaged by polishing on a napped cloth. These observations are in conformity with the conclusions of Weld, Cunningham, and Boswell[8] that the core is simply an area at which a basal section of the radial graphite structure is exposed.

SUMMARY AND DISCUSSION

The stages of the modified system recommended for polishing the more difficult types of cast-iron specimen (those containing coarse graphite) are as follows:

1. *Abrasive Papers*
   Silicon-carbide waterproof papers using flowing water as lubricant:
   (*a*) 220-mesh grade
   (*b*) 400-mesh grade
2. *Intermediate Lap*
   Cast abrasive-wax lap charged with a (10–30)μ grade of levigated alumina. Used dry; hand operated
3. *Diamond Abrasive Stage*
   Paste impregnated with a (0–1)μ grade of diamond abrasive charged on a heavy cotton drill cloth. Kerosene lubricant; hand operated
4. *Magnesium-Oxide Stage*
   "Selvyt" cloth charged with thick paste of calcined magnesium oxide. Hand or machine operated. To be used only when found necessary and where excessive damage to graphite areas does not occur.

The system owes its success both to the improved finish obtained on the intermediate wax lap and, of greater importance, to the use of fast-cutting diamond abrasive on a napless cloth. The finish obtained is a compromise in which maximum retention of graphite is achieved at the expense of the presence of light surface scratches. Such scratches are usually not objectionable in these specimens, even under the most critical conditions of photomicrography.

Figures 1*a–h* are all of specimens which are ordinarily very difficult to prepare, and the standard of the micrographs is thought to be at least the equal of that attained by Morrogh and his co-workers,[1, 2] The present results, however, are achieved by a much less laborious method, no stage of which requires special skill or care. It is also worthy of note that the technique used is that which has been found to give optimum preservation of the edges of the specimen.[5] A process of alternate etching and polishing on a napped cloth must inevitably result in considerable rounding of the specimen edges.

Admittedly the abrasive costs of this method of polishing are appreciably higher than those for the standard method described previously.[3] The cost per specimen nevertheless is still quite low, particularly when compared with other costs of preparation and photography. In any event the improvement in results more than justifies the increased abrasive costs.

Acknowledgment

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Fatigue Tests on Rolled Alloy Steels Made in Electric and Open-Hearth Furnaces

By P. H. Frith, A.Met., F.I.M.

SYNOPSIS

Steels Heat-Treated from 60 to 110 tons/sq. in. U.T.S.

Similar longitudinal and transverse reversed bending fatigue properties were obtained for basic electric-arc (normal-procedure) and acid O.H. steels heat-treated to 60 tons/sq. in. U.T.S. Increasing the U.T.S. to 80 tons/sq. in. did not affect the longitudinal fatigue ratio of neutral or basic O.H. steels, but in the transverse direction the ratio was reduced. A further reduction in the transverse fatigue ratio was obtained by increasing the U.T.S. to 110 tons/sq. in. for basic electric-arc (normal-procedure) and acid and basic O.H. steels, and a reduction in the longitudinal reversed bending ratio was also obtained.

Inclusions of the size and type present in the steels examined did not appear to be detrimental to the reversed bending fatigue properties of the steels heat-treated to 60 tons/sq. in. U.T.S. However, it is considered that extraneous inclusions in massive form will most probably be detrimental to the fatigue properties of these steels. At 80 tons/sq. in. U.T.S. the inclusions present in the steels examined began to be detrimental to the transverse reversed bending fatigue properties, and at 110 tons/sq. in. U.T.S. they were detrimental to both the longitudinal and transverse properties.

Undeformed spherical silicates appeared to be the most detrimental inclusions from a fatigue viewpoint, producing at least 17% reduction in the longitudinal fatigue limit of basic electric-arc (normal-procedure) steel heat-treated to 110 tons/sq. in. U.T.S.

Steels Heat-Treated to 750 D.P.N.

The fatigue tests carried out in the longitudinal direction showed that the best fatigue properties were fairly consistently obtained from neutral or acid O.H. steel, or steel manufactured in a basic-lined electric-arc furnace using a siliceous slag. Similar fatigue properties were also obtained on one cast of acid electric-arc steel. The fatigue limit of British basic electric-arc (normal-procedure) steel was 26% lower than for British neutral O.H. steel, whilst two Swedish acid O.H. steels had slightly inferior fatigue properties to the British neutral steel. These low fatigue properties obtained on British basic electric-arc (normal-procedure) steel appeared to be due to undeformed spherical silicate inclusions.

Tests were also made on various types of steel to determine the effect on the fatigue properties of overstressing, understressing, shot peening, retained austenite, repeated impact loading, and variations in the hardening and tempering treatments. A few tests were also carried out on specimens obtained from different positions of an ingot and from different ingots of the same cast. 1068

THIS INVESTIGATION was carried out in two separate sections. The first section consisted of tests on steels heat-treated to 60, 80, or 110 tons/sq. in. U.T.S., and it was initiated in 1939 by the Inclusions Sub-Committee of The Iron and Steel Institute. Bars of approx. 5-in. gothic section were supplied for the tests, the steel being manufactured in the U.K. using the following types of furnace:

(i) Basic electric-arc (normal procedure)
(ii) Acid open-hearth (A.O.H.)
(iii) Basic open-hearth (B.O.H.)
(iv) Neutral open-hearth (N.O.H.).

These steels were manufactured by an approved method in regard to type of ingot, feeder head, and thermal treatments, and revealed a high degree of cleanness. The specimens for the fatigue tests were obtained in both the longitudinal and transverse directions from near the outside of the bar, and for the tests on the 60 tons/sq. in. U.T.S. steels four different fatigue machines were used. Tests were also carried out with both reversed bending and reversed torsional stresses. However, the tests on the steels heat-treated to 80 or 110 tons/sq. in. U.T.S. and 750 D.P.N. were only carried out with reversed bending stresses on a Wöhler-type machine using the rotating uniform bending test piece. This type of fatigue test was used because it enabled a much greater surface area to be tested than with the cantilever specimens used on the other machines. Therefore in this short summary of the Report only the rotating uniform bending test results are given.

In addition to the mechanical tests, a metallographic

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examination was carried out on the various steels to determine the Fox inclusion count and the types of inclusion present. Metallographic tests were also carried out on numerous test pieces when it was suspected that fracture had begun at an inclusion.

The second section consisted of tests on C–Cr steels heat-treated to about 750 D.P.N., and this section was initiated in 1944 by the Bristol Aeroplane Co., Ltd. Bars of $\frac{3}{4}$–1 in. dia. or tube of $7\frac{9}{16}$ in. outside dia. × $6\frac{1}{16}$ in. inside dia. were obtained for these tests. The steels were manufactured in the U.K. by an approved method to produce a high degree of cleanness as for the lower tensile steels, using the following types of furnace:

(i) Basic electric-arc (normal procedure)
(ii) Basic electric-arc (modified procedure)
(iii) Electric-arc (modified procedure)
(iv) Acid electric-arc
(v) Acid high-frequency (A.H.F.)
(vi) A.O.H.
(vii) N.O.H.

Tests were also carried out on A.O.H. steels manufactured in Sweden. The steels listed as basic electric-arc (modified-procedure) were manufactured with various alterations made to the normal process, whilst the electric-arc (modified-procedure) steels were manufactured in a basic-lined furnace using a siliceous slag, instead of the normal lime silicate slag.

The fatigue tests on all the steels heat-treated to about 750 D.P.N. were carried out in the longitudinal direction. Thirteen fatigue limits were determined on various types of steel, and then tests were carried out on 75 casts with reversed bending stresses of ± 45, ± 50, or ± 55 tons/sq. in. These casts were made in various types of furnace, and the tests were carried out to explore the variations obtained by the same and different steelmaking processes.

When the test pieces were finished-machined, magnetic and X-ray diffraction tests were made on most of the specimens to determine whether there was any correlation between the presence of retained austenite and the fatigue properties. The metallographic examination to determine the types of inclusions present in these 750 D.P.N. steels was carried out on only three test series. However, microradiographic tests were made on a number of test series, to determine whether there was any correlation between the types of inclusion revealed by this form of test and the fatigue properties.

DISCUSSION OF RESULTS

Steels Heat-Treated from 60 to 110 tons/sq. in. U.T.S.

The fatigue properties obtained are given in Table I. These test results showed that for the 60 and 80 tons/sq. in. U.T.S. steels the longitudinal fatigue ratios were very consistent for eight electric-arc or O.H. steels (0·52–0·55), even though the Fox inclusion count varied from 28 to 104. However, increasing the U.T.S. to 110 tons/sq. in. reduced the ratio to about 0·40 for A.O.H. or B.O.H. steel (Fox count 93), and to about 0·33 for basic electric-arc (normal-procedure) steel (Fox count 28 or 60). Therefore, from a longitudinal fatigue point of view, very little benefit was obtained by increasing the U.T.S. above 80 tons/sq. in.

There was no obvious relationship between the longitudinal fatigue limit and the Fox inclusion count for steels heat-treated up to 110 tons/sq. in. U.T.S. The increased inclusion counts for these steels were mainly due to an increase in the sulphur content up to 0·04%, which increased the number of manganese sulphide inclusions. Therefore, it appeared that the fatigue limits of these steels were unaffected by the number of the manganese sulphide inclusions. This indicated that these inclusions may be ignored when making inclusion counts of steels similar to those used in this present investigation. However, when they occurred as part of a duplex inclusion they would have to be included. It also appeared from these tests that a modified metallographic method of inclusion counting which gives a numerical value to the type of inclusion, or to a combination of the type and size, might be more informative. Also, an inclusion count determined by a microradiographic examination appeared to be worthy of consideration.

For the tests in the transverse direction, the fatigue limit remained practically constant as the U.T.S. was increased from 60 to 110 tons/sq. in. The fatigue ratios obtained were approx. 0·42, 0·37, and 0·25 for the 60, 80, and 110 tons/sq. in. U.T.S. steels, respectively. Therefore, from a fatigue point of view, it appears that the attainment of a satisfactory forging grain flow becomes even more essential as the U.T.S. is raised above 60 tons/sq. in.

From the metallographic examination to determine the types of inclusion present in the various steels, no correlation was observed between any particular type of inclusion and the fatigue properties. However, the examination did show that the shapes of the inclusions could be divided into three groups. In the first group were those inclusions which deformed during hot-working and became elongated. The second group consisted of those inclusions which did not deform during hot-working, whilst the third group included those undeformed inclusions of the second group which had a manganese sulphide envelope that deformed. From a stress-concentration point of view, it was considered that the cavities produced by the undeformed inclusions of the second group or the undeformed inclusions of the third group which protruded out of the manganese sulphide envelope were the most detrimental to the fatigue properties. These undeformed inclusions included hard angular alumina or alumino silicates, titanium cyano-nitride, quartz, and spherical silicates. Microradiographic and metallographic tests on steels heat-treated to about 750 D.P.N. showed that the spherical silicate type of inclusion could produce sharp angular diamond-shaped cavities in the material during hot-working, as shown in Fig. 1. These inclusions were more liable to be present in basic electric-arc (normal-procedure) steel than in O.H. steel, but they were not detrimental to the fatigue properties of steels heat-treated to 60 tons/sq. in. U.T.S. However, the longitudinal fatigue limit of steel heat-treated to 110 tons/sq. in. U.T.S. appeared to be reduced at least 17% by these inclusions.

Fifteen test pieces were shown by current flow and magnetic flow tests to have inclusions on the surface

Table I

TENSILE AND FATIGUE PROPERTIES OBTAINED ON STEELS HEAT-TREATED TO APPROX. 60, 80, OR 110 tons/sq. in. U.T.S.

Approx. U.T.S., tons/sq. in.	Type of Steel	Chemical Analysis to Specification	Test Series	Fox Inclusion Count	Heat-Treatment‡			Tensile Properties						Fatigue Properties (Reversed Bending)				Decrease in Fatigue Limit due to Testing in Transverse instead of Longitudinal Direction, %
					Initial Treatment (3-hr. Soak)	Hardening Treatment (1-hr. Soak)	Tempering Treatment (1- or 1-hr. Soak)	Longitudinal			Transverse			Fatigue Limit, tons/sq. in.		Fatigue Ratio*		
								0·1% Proof Stress	U.T.S.	Elongation, %	0·1% Proof Stress	U.T.S.	Elongation, %	Longitudinal	Transverse	Longitudinal	Transverse	
								tons/sq. in.			tons/sq. in.							
60	Basic electric-arc (normal procedure) A.O.H.	S11	*EB1/A*	28	...	830° C. (O)	650° C. (O)	42·9	62·6	26·0	46·6	62·6	21·0	±32·5	±29·0	0·52	0·46	11
			EB2	74	...	830° C. (O)	585° C. (O)	53·2	61·3	21·0	56·4	63·8	15·0	±33·5	±27·0	0·55	0·42	19
			EB3	38	...	830° C. (O)	607° C. (O)	53·4	60·3	18·0	51·5	63·4	17·0	±31·5	±25·25	0·52	0·40	20
			EB4	37	...	830° C. (O)	610° C. (O)	53·0	61·0	17·0	52·4	61·9	16·0	±32·0	±24·0	0·52	0·39	25
		S11	*OA1*	104	...	830° C. (O)	620° C. (O)	50·0	61·3	12·0†	46·3	57·1	21·0	±33·0	±24·75	0·54	0·43	25
			OA2	100	...	830° C. (O)	655° C. (O)	54·2	61·0	17·0	51·7	61·1	13·0	±33·5	±25·5	0·55	0·42	24
80	N.O.H.	En. 25	*ON1*	80	...	830° C. (O)	575° C. (O)	72·7	79·0	15·0	74·9	82·0	11·0	±41·25	±29·25	0·52	0·36	29
	B.O.H.	En. 26	*OB1/A*	...	...	830° C. (O)	590° C. (O)	69·8	79·1	21·0	68·7	74·5	7·0	±42·0	±29·0	0·53	0·39	31
110	Basic electric-arc (normal procedure) A.O.H.	S11	*EB1/B*	28	...	830° C. (A)	200° C. (A)	75·8	113·9	16·0	73·9	119·0	11·5	±38·0	±30·0	0·33	0·25	21
			EB1/C	28	...	830° C. (A)	200° C. (A)	81·1	108·1	15·5	...	...	...	±40·0	...	0·37	...	...
							250° C. (A)											
			EB1/D	28	1200° C. (F)	830° C. (A)	200° C. (A)	81·0	118·1	13·0	...	...	...	±36·0 (approx.)	...	0·30 (approx.)	...	...
		S28	*EB5*	60	...	820° C. (A)	200° C. (A)	72·7	127·1	12·5	75·8	109·1	9·0	±40·5	±27·0	0·32	0·25	33
		S28	*OA3*	93	...	820° C. (A)	200° C. (A)	73·0	113·0	14·0	83·1	111·8	4·0	±45·5	±29·25 (approx.)	0·40	0·26 (approx.)	36 (approx.)
	B.O.H.	En. 26	*OB1/B*	...	...	830° C. (A)	200° C. (A) 250° C. (A)	92·6	120·7	9·0	88·1	120·0	3·0	±47·0	±27·5	0·39	0·23	41

* Fatigue ratio = (Fatigue limit)/(U.T.S.).
† Broke outside gauge length
‡ O = Oil-quenched; *A* = Air-cooled; *F* = Furnace-Cooled.

before fatigue testing. Two of the test pieces were heat-treated to 60 tons/sq. in. U.T.S., eleven to 80 tons/sq. in., and two to 110 tons/sq. in., but only with one specimen was fracture initiated at one of these surface inclusions; this test piece was heat-treated to 80 tons/sq. in. U.T.S. Therefore, from these test results it appeared that surface inclusions were not very detrimental to the fatigue properties. This statement, of course, only applies to the size and type of inclusions present in the steels used for this investigation, and does not apply to inclusions in massive form which are sometimes found. However, fracture was occasionally initiated by an inclusion just below the surface, for the transverse tests on the steels heat-treated to 80 tons/sq. in. U.T.S., and was frequently initiated by this type of inclusion for the longitudinal and transverse tests on steels heat-treated to 110 tons/sq. in. U.T.S. Therefore, it appears that inclusions just below the surface may be more detrimental to the fatigue properties of steels heat-treated to 110 tons/sq. in. U.T.S. than inclusions on the surface. This is probably due to accommodating slip reducing the stress concentration produced by an inclusion on the surface, but not just below the surface. When fracture was initiated below the surface a white circular area was visible on the fracture face. With the longitudinal test pieces there appeared to be an inclusion towards the centre of the white area, whilst with the transverse test pieces an inclusion was frequently found across the white area. This indicated that for the transverse tests fracture was initiated towards the centre of the inclusion and not at the ends, and there was some evidence that this also occurred with the longitudinal test pieces. It was considered that these white areas were formed by a very slow propagation of the fracture until it reached or nearly reached the surface. Then the

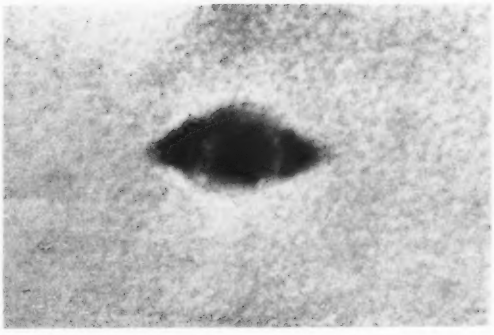
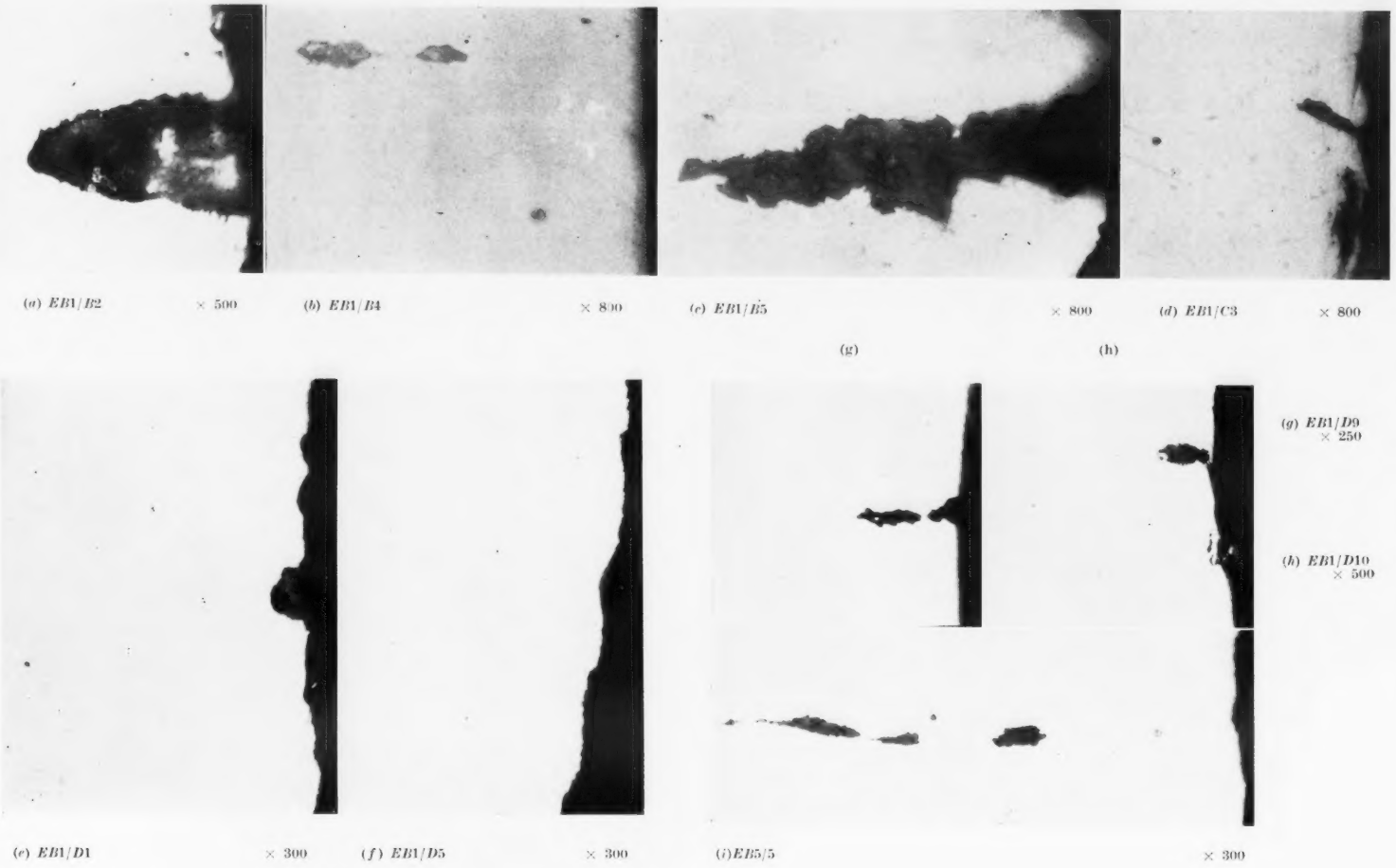


Fig. 1—Diamond-shaped cavity produced by spherical inclusion



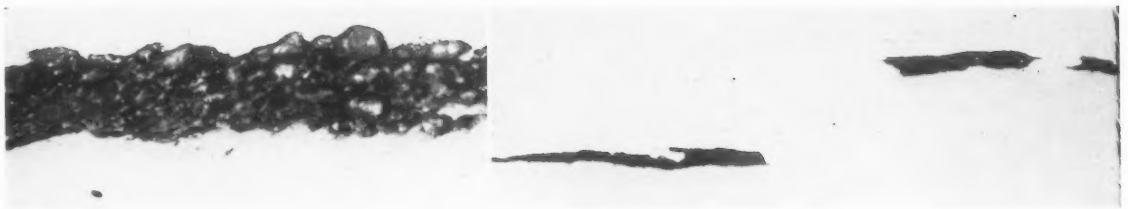
(a) *EB1/B2* × 500 (b) *EB1/B4* × 800 (c) *EB1/B5* × 800 (d) *EB1/C3* × 800

(e) *EB1/D1* × 300 (f) *EB1/D5* × 300 (g) *EB1/D9* × 250 (h) *EB1/D10* × 500 (i) *EB5/5* × 300

Fig. 2—Inclusions observed at the start of the fatigue fractures

(*j*) *EB5/8* × 1000 (*k*) *EB5/9* × 300 (*l*) *OA3/5* × 55

(*m*) *OA3/5* × 290 (*n*) *OA3/6* × 100



(*o*) *OA3/6* × 500 (*p*) *OB1/B5* × 100

Fig. 2 (*contd.*)—Inclusions observed at the start of the fatigue fractures

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Table II

FATIGUE PROPERTIES OBTAINED ON STEELS HEAT-TREATED TO APPROX. 750 D.P.N.

Type of Steel	Chemical Analysis to Specification	Test Series	Heat-Treatment		Magnetic Test: Saturation Value (B_S), Gauss	Actual Hardness, D.P.N. (H_D/5)	Longitudinal Fatigue Limit (Reversed Bending), tons/sq. in.
			Rough Machined Test Pieces*	Finished Machined Test-Pieces			
Basic electric-arc (normal procedure)—British	En. 31	*EB6/A*	*A*	...	14,250	819	± 37·5
		EB6/B	*A*	Immersed in liquid oxygen (4 hr.)	14,660	816	± 38·5
		EB6/C	*A*	Immersed in liquid oxygen (2¼ hr.); 250° C. (1 hr. soak), A.C.	18,490	748	± 38·0 (approx.)
		EB6/D	*C*	Immersed in liquid oxygen (30 min.)	19,580	741	± 37·5
A.H.F.—British	En. 31	*HFA1/A*	*B*	...	21,420	760	± 45·0
		HFA1/B	*C*	Immersed in liquid oxygen (30 min.)	20,880	665	± 42·0
	En. 31 + 2% Co	*HFA2/A*	*B*	...	21,630	751	± 39·5
		HFA2/B	*C*	Immersed in liquid oxygen (30 min.)	20,670	662	± 39·0
A.O.H.—Swedish	En. 31	*OA4/A*	*A*	...	18,980	808	± 47·0
		OA4/B	*C*	Immersed in liquid oxygen (30 min.)	21,170	746	± 44·0
		OA5/A	*A*	...	18,690	866	± 43·5
		OA5/B	*C*	Immersed in liquid oxygen (30 min.)	21,750	728	± 41·0
N.O.H.—British	En. 31	*ON2*	*A*	...	18,840	831	± 51·0

*Heat-treatment: (*A*) 850° C. (½-hr. soak), O.Q. (50–60° C.).
Stood 2 days.
Immersed in solid carbon dioxide (½ hr.).
Stood 2 days.
185° C. (1-hr. soak), A.C.

(*B*) 850° C. (½-hr. soak), O.Q. (50–60° C.).
Stood 2 days.
Immersed in solid carbon dioxide (½-hr.).
Stood 2 days.
250° C. (1-hr. soak), A.C.

(*C*) 800° C. (½-hr. soak), O.Q. (50–60° C.).
Removed from oil after 10 min.
Cleaned and immersed in liquid oxygen.
Removed after 30 min.
250° C. (1-hr. soak), A.C.

mode of propagation was altered, producing a normal type of fracture.

The metallographic examination of the fatigue test pieces which had a white area on the fracture face showed that 34 specimens had an inclusion at, or associated with, the origin of the fatigue fracture. For 28 test pieces the inclusion was of the silicate or duplex silicate type, and the accidental refractory type of inclusion was found in five specimens. The remaining test piece had an alumina inclusion. As previously stated the rotating uniform bending type of test piece was used for these tests, the critical section being 1 in. long. This enabled a reasonable surface area to be uniformly stressed during the test, and as the failures were initiated up to 0·026 in. below the surface, fracture could occur in an appreciable volume of metal. Although the metallographic examination to determine the types of inclusion present in the steels showed that various types were present, when fracture was initiated at an inclusion, 82% of these inclusions were of the silicate or duplex silicate types. Therefore, it again appears that this type of inclusion is the most detrimental from a fatigue viewpoint. This type of inclusion has previously been considered to be the most detrimental from a fatigue point of view when in the spherical form. An examination of Fig. 2 shows that in a few examples, especially for the basic electric-arc (normal-procedure) steels, the inclusion observed at the start of the fracture may have been spherical with or without associated end cavities. Also, Fig. 2 appears to indicate that the silicate inclusions observed in the O.H. steels had deformed during hot-working much more than in the basic electric-arc (normal-procedure) steels. It has previously been stated that it is considered that undeformed inclusions produce cavities which are more detrimental from a fatigue point of view than the deformable type of inclusion. Therefore, although the silicate type of inclusion was observed at the origin of the fatigue fracture in both basic electric-arc (normal-procedure) and O.H. steels, it may be that the lower longitudinal fatigue properties of the former steel were due to less deformation of the silicate inclusions.

Steels Heat-Treated to about 750 D.P.N.

As previously stated, the first series of fatigue tests was carried out to determine fatigue limits, and the results obtained are given in Table II. These test results show that the fatigue limit of basic electric-arc (normal-procedure) steel was about ± 38 tons/sq. in., and it was unaffected by variations in the heat-treatment. It is interesting to note the similarity between the longitudinal fatigue limits obtained on this steel heat-treated to 750 D.P.N., and the fatigue

Table III

FATIGUE PROPERTIES OBTAINED ON STEELS
Chemical Analysis to

Heat-Treatment of Rough Machined Test Pieces:
850° C. (½-hr. soak), O.Q. (50–60° C.).
Stood 2 days.

Type of Steel	Magnetic Test: Mean Saturation Value (B_S), Gauss	Hardness Test: Mean D.P.N. Value ($H_D/5$)	Number of Casts Tested	Number of Casts Unbroken for 20×10^6 cycles at $\pm$ 50·0 tons/sq. in.	Longitudinal Fatigue-Test		
					$\pm$ 45·0 tons/sq. in.		
					Cycles $\times 10^6$		
Basic electric-arc (normal-procedure)	22,860	771	16	1 (6%)	0·15 *B* (*EB* 9) 1·58 *B* (EB 15) 6·44 *B* (*EB* 19) 6·74 *B* (*EB* 9) 8·08 *B* (*EB* 14) 13·33 *B* (*EB* 19) 50·78 *UB* (*EB* 17)	1·42 *B* (*EB* 10) 4·72 *B* (*EB* 22) 6·49 *B* (*EB* 11) 7·22 *B* (*EB* 20) 10·71 *B* (*EB* 18) 20·46 *UB* (*EB* 20)	1·51 *B* (*EB* 9) 5·03 B (*EB* 12) 6·69 *B* (*EB* 16) 7·62 B (*EB* 21) 11·15 *B* (*EB* 7) 48·24 *UB* (*EB* 13)
Basic electric-arc (modified-procedure)	21,370	749	13	3 (23%)	1·41 *B* (*EBM* 4) 9·05 *B* (*EBM* 9) 20·92 *B* (*EBM* 5) 33·16 *UB* (*EBM* 1)	3·67 *B* (*EBM* 8) 20·13 *UB* (*EBM* 6) 27·07 *UB* (*EBM* 3)	6·17 *B* (*EBM* 10) 20·68 *UB* (*EBM* 7) 29·29 *UB* (*EBM* 11)
Electric-arc (modified-procedure)	22,500	750	12	11 (92%)	4·40 *B* (*EM*6)	10·51 *B* (*EM* 6)	
Acid electric-arc	22,900	760	1	1 (100%)			
A.H.F.	22,540	776	1	0 (0%)	5·08 *B* (*HFA*3)	25·41*UB* (*HFA*3)	
A.O.H.	22,410	754	5	3 (60%)	21·69 *B* (*OA* 7)	31·87 *UB* (*OA* 9)	
N.O.H.	22,110	761	27	19 (70%)	13·58 *B* (*ON* 10) 20·05 *UB* (*ON* 8) 25·77 *UB* (*ON* 12)	19·13 *B* (*ON* 13) 20·23 *UB* (*ON* 15) 26·91 *UB* (*ON* 21)	19·79 *B* (*ON* 12) 21·17 *UB* (*ON* 27) 29·81 *UB* (*ON* 9)

* *B* = Broken; *UB* = Unbroken.

The test series are given in brackets after the number of cycles.

limits obtained on basic electric-arc (normal-procedure) steels heat-treated to 110 tons/sq. in. U.T.S. (523–600 D.P.N.). One cast of A.H.F. steel (*HFA*1) gave slightly higher fatigue limits than the basic electric-arc (normal-procedure) steel, whilst A.O.H. or N.O.H. steels had the best fatigue properties. The fatigue limit obtained for the basic electric-arc (normal-procedure) steel was 26% lower than for N.O.H. steel after a similar heat-treatment.

The two A.O.H. steels were made in Sweden, whilst the remaining steels were of British manufacture. These Swedish steels had higher longitudinal fatigue properties than British basic electric-arc (normal-procedure) steel, but slightly inferior properties to British N.O.H. steel. Similar conclusions were obtained on a further cast of Swedish steel, tested in the second series (*OA*10 in Table III).

The second series of fatigue tests on the steels heat-treated to 750 D.P.N. were carried out with reversed bending stresses of $\pm$ 45, $\pm$ 50, or $\pm$ 55 tons/sq. in. These tests were carried out to explore the variations obtained by the same and different steelmaking processes. The first test on each cast was made at a stress of $\pm$ 50 tons/sq. in., which is just below the fatigue limit obtained for the N.O.H. steel. If this remained unbroken for 2×10^7 cycles, a second test was carried out with a stress of $\pm$ 55 tons/sq. in. This test was again discontinued if it remained unbroken after 2×10^7 cycles. However, if the first test piece broke, the second test was made with a stress of $\pm$ 45 tons/sq. in., and this test was also discontinued if unbroken after 2×10^7 cycles. The results obtained for these tests are given in Table III.

The tests again showed that basic electric-arc (normal-procedure) steels had inferior fatigue properties to A.O.H. or N.O.H. steels. Sixteen casts of the former type of steel were tested, and only one cast (6%) withstood 2×10^7 cycles with a reversed bending stress of $\pm$ 50 tons/sq. in. Modifying the steelmaking process in various ways resulted in 23% of the casts tested withstanding 2×10^7 cycles under the same test conditions. Further improvement in the fatigue properties of this type of steel was obtained by using a siliceous slag instead of the normal lime silicate slag, as 92% of these casts withstood 2×10^7 cycles at $\pm$ 50 tons/sq. in. Therefore, the tests on these electric-arc steels showed that the fatigue properties could be varied quite considerably by modifying the steelmaking process. Unfortunately, full details of the actual processes

Table III (*continued*)

HEAT-TREATED TO APPROX. 750 D.P.N.
Specification En. 31

Immersed in solid carbon dioxide (¼ hr.)
Stood 2 days.
250° C. (1-hr. soak), A.C.

Results* with a Reversed Bending Stress of

± 50·0 tons/sq. in.						± 55·0 tons/sq. in.					
Cycles × 10^6						Cycles × 10^6					
0·24 *B*	(*EB* 18)	0·28 *B*	(*EB* 19)	0·37 *B*	(*EB* 15)	24·70 *UB*	(*EB* 8)				
0·66 *B*	(*EB* 9)	0·84 *B*	(*EB* 9)	0·93 *B*	(*EB* 16)						
0·97 *B*	(*EB* 7)	1·06 *B*	(*EB* 12)	1·13 *B*	(*EB* 22)						
1·28 *B*	(*EB* 9)	1·44 *B*	(*EB* 11)	1·54 *B*	(*EB* 10)						
1·79 *B*	(*EB* 14)	2·13 *B*	(*EB* 19)	2·81 *B*	(*EB* 20)						
3·37 *B*	(*EB* 20)	3·65 *B*	(*EB* 13)	4.59 *B*	(*EB* 17)						
5·19 *B*	(*EB* 21)	42·78 *UB*	(*EB* 8)								
0·34 *B*	(*EBM* 7)	0·41 *B*	(*EBM* 8)	0·98 *B*	(*EBM* 10)	0·46 *B*	(*EBM* 13)	0·71 *B*	(*EBM* 12)	3·85 *B*	(*EBM* 2)
1·23 *B*	(*EBM* 9)	1·70 *B*	(*EBM* 5)	3·96 *B*	(*EBM* 11)						
4·88 *B*	(*EBM* 3)	8·61 *B*	(*EBM* 4)	9·70 *B*	(*EBM* 6)						
18·81 *B*	(*EBM* 1)	20·49 *UB*	(*EBM* 2)	24·73 *UB*	(*EBM* 13)						
30·22 *UB*	(*EBM* 12)										
0·48 *B*	(*EM* 6)	0·66 *B*	(*EM* 6)	20·10 *UB*	(*EM* 4)	1·97 *B*	(*EM* 3)	3·24 *B*	(*EM* 12)	9·14 *B*	(*EM* 7)
20·25 *UB*	(*EM* 10)	20·35 *UB*	(*EM* 12)	20·40 *UB*	(*EM* 8)	20·39 *UB*	(*EM* 5)	20·72 *UB*	(*EM* 9)	22·34 *B*	(*EM* 1)
20·42 *UB*	(*EM* 9)	20·90 *UB*	(*EM* 7)	21·03 *UB*	(*EM* 5)	24·36 *B*	(*EM* 7)	24·62 *UB*	(*EM* 8)	27·77 *UB*	(*EM* 10)
22·87 *UB*	(*EM* 2)	24·62 *UB*	(*EM* 11)	25·10 *UB*	(*EM* 7)	27·97 *UB*	(*EM* 4)	28·83 *UB*	(*EM* 11)	31·36 *UB*	(*EM* 2)
25·45 *UB*	(*EM* 3)	28·91 *UB*	(*EM* 1)								
21·31 *UB*	(*EA* 1)					14·59 *B*	(*EA* 1)	29·74 *UB*	(*EA* 1)		
8·57 *B*	(*HFA* 3)	18·03 *B*	(*HFA* 3)								
0·63 *B*	(*OA* 7)	3·27 *B*	(*OA* 9)	20·41 *UB*	(*OA* 9)	3·42 *B*	(*OA* 9)	4·14 *B*	(*OA* 10)	5·97 *B*	(*OA* 8)
24·76 *UB*	(*OA* 8)	29·41 *UB*	(*OA* 6)	29·58 *UB*	(*OA* 10)	12·00 *B*	(*OA* 6)	28·74 *UB*	(*OA* 8)	38·52 *B*	(*OA* 8)
31·24 *UB*	(*OA* 8)	46·55 *UB*	(*OA* 8)								
0·14 *B*	(*ON* 12)	0·24 *B*	(*ON* 13)	1·19 *B*	(*ON* 21)	0·33 *B*	(*ON* 10)	0·41 *B*	(*ON* 18)	0·98 *B*	(*ON* 9)
1·63 *B*	(*ON* 8)	2·94 *B*	(*ON* 27)	3·62 *B*	(*ON* 12)	2·28 *B*	(*ON* 7)	4·02 *B*	(*ON* 29)	15·45 *B*	(*ON* 6)
14·79 *B*	(*ON* 7)	17·59 *B*	(*ON* 15)	20·02 *UB*	(*ON* 16)	16·50 *B*	(*ON* 19)	17·60 *B*	(*ON* 5)	20·01 *UB*	(*ON* 11)
20·04 *UB*	(*ON* 17)	20·15 *UB*	(*ON* 6)	20·23 *UB*	(*ON* 19)	21·18 *UB*	(*ON* 28)	21·84 *UB*	(*ON* 17)	22·62 *B*	(*ON* 22)
21·22 *UB*	(*ON* 24)	21·54 *UB*	(*ON* 18)	22·85 *UB*	(*ON* 5)	24·33 *UB*	(*ON* 3)	25·66 *UB*	(*ON* 24)	26·85 *UB*	(*ON* 16)
24·26 *UB*	(*ON* 4)	24·48 *UB*	(*ON* 3)	24·94 *B*	(*ON* 22)	26·94 *B*	(*ON* 23)	29·08 *UB*	(*ON* 25)	29·13 *UB*	(*ON* 26)
25·65 *UB*	(*ON* 23)	25·88 *UB*	(*ON* 14)	26·24 *B*	(*ON* 9)	29·88 *UB*	(*ON* 20)	33·76 *UB*	(*ON* 14)	39·74 *UB*	(*ON* 4)
28·90 *UB*	(*ON* 26)	28·92 *UB*	(*ON* 25)	28·97 *UB*	(*ON* 28)						
29·18 *UB*	(*ON* 29)	29·22 *UB*	(*ON* 20)	36·52 *UB*	(*ON* 11)						

All the steels except *OA* 10 were manufactured in the U.K.; *OA* 10 was manufactured in Sweden.

used could not be obtained from the various steelmakers for this paper.

One cast of acid electric-arc steel gave very good fatigue properties. It is interesting to note the similarity of the fatigue results obtained for this type of steel and steel made in a basic-lined furnace using a siliceous acid slag. However, as only one cast of acid electric-arc steel was submitted for test, it was not possible to assess the variation in fatigue properties between different casts of this steel. Similarly, the variation between different casts of A.H.F. steel could not be determined, but the results obtained indicated that the fatigue properties were superior to basic electric-arc (normal-procedure) steel, but inferior to A.O.H. or N.O.H. steel.

With the A.O.H. steels, 60% of the casts tested remained unbroken for 2×10^7 cycles with a reversed bending stress of $\pm$ 50 tons/sq. in. For the N.O.H. steels the figure was slightly higher (70%). Therefore, ignoring the fatigue results obtained on the one cast of acid electric-arc steel, it appears that the best fatigue properties for C–Cr steel heat-treated to 750 D.P.N. are obtained from material made in a N.O.H. or A.O.H. furnace, or in a basic-lined electric-arc furnace using a siliceous slag. However, even with these steelmaking methods it is possible occasionally to obtain low fatigue properties, and therefore it appears necessary to have a fatigue test in the specification for this material. A suitable clause would appear to be that the test piece should remain unbroken after 5×10^6 cycles with a reversed bending stress of $\pm$ 55 tons/sq. in. The test piece should preferably be of the rotating uniform bending type.

In addition to the fatigue tests previously described, a few tests were carried out to determine:

(i) Repeated impact transverse properties of British basic electric-arc (normal-procedure), British N.O.H., and Swedish O.H. steels

(ii) Effect of overstressing, understressing, and shot peening on the fatigue properties

(iii) Fatigue properties from different positions of an ingot, and from different ingots of the same cast.

The metallographic examination, which was carried out on only three basic electric-arc (normal-procedure) steels, showed that these steels contained spherical silicate and/or titanium cyano-nitride inclusions. These have previously been referred to as inclusions of the second group, which are considered to produce cavities detrimental to the fatigue properties.

Although only a limited amount of metallographic work was carried out on these 750 D.P.N. steels, a

fairly complete microradiographic examination was made. The results obtained are given in Table IV. These tests showed that all the basic electric-arc (normal-procedure) steels examined contained what appeared to be diamond-shaped 'inclusions.' However, a more extensive investigation showed that these so-called diamond-shaped 'inclusions' were in fact spherical inclusions with associated end cavities. The end cavities were occasionally filled with a siliceous type of inclusion which had deformed during the rolling operation, but the spherical inclusions had not deformed to any appreciable extent during hot-working.

With the basic electric-arc (normal-procedure) steel there was no correlation between the number of the spherical inclusions and the fatigue properties. With even a few small inclusions of this type, the maximum number of cycles obtained with a reversed bending stress of ± 50 tons/sq. in. was less than 5×10^6. Similar fatigue results were obtained with the basic

Table IV

MICRORADIOGRAPHIC RESULTS OBTAINED ON STEELS HEAT-TREATED TO APPROXIMATELY 110 tons/sq. in. U.T.S. OR 750 D.P.N.

Steel Heat-Treated to Approximately	Chemical Analysis to Specification	Type of Steel	Test Series	Longitudinal Fatigue Test Results				Remarks on Diamond-shaped 'Inclusions'‡ Observed by Microradiographic Examination
				Fatigue Limit (Reversed Bending), tons/sq.in.	Number of Cycles ($\times 10^6$) with Reversed Bending Stress* of			
					± 45·0 tons/sq.in.	± 50·0 tons/sq.in.	± 55·0 tons/sq.in.	
110 tons/sq. in. U.T.S.	S 11	Basic electric-arc (normal procedure)	*EB*1/*B*	± 38·0	...	...	...	Few (very small)
	S 28	A.O.H.	*OA* 3	± 45·5	...	...	...	None
	En. 26	B.O.H.	*OB*1/*B*	± 47·0	...	...	...	None
750 D.P.N.	En. 31	Basic electric-arc (normal-procedure)	*EB* 9	...	6·74 *B*	0·66 *B*	...	Numerous (large and small)
			EB 10	...	1·42 *B*	1·54 *B*	...	Numerous (large)
			EB 12	...	5·03 *B*	1·06 *B*	...	Numerous (large)
			EB 13	...	48·24 *UB*	3·65 *B*	...	Numerous (large)
			EB 14	...	8·08 *B*	1·79 *B*	...	Few (large)
			EB 15	...	1·58 *B*	0·37 *B*	...	Numerous (large)
			EB 17	...	50·78 *UB*	4·59 *B*	...	Few (small)
			EB 18	...	10·71 *B*	0·24 *B*	...	Numerous (large)
			EB 19	...	6·44 *B*	0·28 *B*	...	Numerous (large)
				...	13·33 *B*	2·13 *B*	...	Numerous (large)
			EB 20	...	20·46 *UB*	2·81 *B*	...	Numerous (large and small)
		Basic electric-arc (modified procedure)	*EBM* 1	...	33·16 *UB*	18·81 *B*	...	None
			EBM 9	...	9·05 *B*	1·23 *B*		Few (small)
			EBM 10	...	6·17 *B*	0·98 *B*	...	Few (small)
			EBM 11	...	29·29 *UB*	3·96 *B*	...	Several (large)
			EBM 12	...	...	30·22 *UB*	0·71 *B*	No definite diamond-shaped 'inclusions,' but a few small inclusions which had a reduced angular profile and no end cavities
			EBM 13	...	...	24·73 *UB*	0·46 *B*	
		Electric - arc (modified-procedure)	*EM* 1	...	...	28·91 *UB*	22·34 *B*	None
			EM 2	...	...	22·87 *UB*	31·36 *UB*	None
			EM 6	...	10·51 *B*	0·48 *B*	...	Numerous (large and small)
			EM 7	...	...	20·90 *UB*	9·14 *B*	None
		Acid electric-arc	*EA* 1	...	...	21·31 *UB*	14·59 *B*	None
		A.H.F.	*HFA* 3	...	25·41 *UB*	8·57 *B*	...	None
		A.O.H.	*OA* 6	...	...	29·41 *UB*	12·00 *B*	None
			OA 7	...	21·69 *B*	0·63 *B*	...	None
			OA 8	...	...	46·55 *UB*	5·97 *B*	None
		N.O.H.	*ON* 2	...	...	168·05 *UB*†	65·76 *B*	None
			ON 3	...	...	24·48 *UB*	24·33 *UB*	None
			ON 6	...	...	20·15 *UB*	15·45 *B*	None
			ON 7	...	...	14·79 *B*	2·28 *B*	None
			ON 10	...	13·58 *B*	..	0·33 *B*	None

* *B* = broken; *UB* = unbroken.
† ± 51·0 tons/sq.in.
‡ The large diamond-shaped 'inclusions' were over 0·0015 in. long.

electric-arc (modified-procedure) steels, when these spherical inclusions were present (test series *EBM* 9, 10, 11). However, with test series *EBM* 1, which did not contain this type of inclusion, the number of cycles to fracture was $18{\cdot}81 \times 10^6$.

Two of the basic electric-arc (modified-procedure) steels (test series *EBM* 12, 13) contained no definite spherical inclusions, but a few small inclusions were observed which had a reduced angular profile, with no observable end cavities. These inclusions had obviously deformed to a certain extent during rolling, and there was evidence in one instance that the inclusion was of the duplex type with a deformable outer envelope. The fatigue test piece from both these casts with a reversed bending stress of $\pm$ 50 tons/sq. in. remained unbroken for about 25×10^6 cycles. This was a considerable improvement over the maximum life of 5×10^6 cycles, obtained when the non-deformable type of inclusion was present.

With the electric-arc (modified-procedure) steels, which were made in a basic-lined electric-arc furnace using a siliceous slag, improved fatigue properties were obtained. In all, 12 casts were tested, and the test piece stressed at $\pm$ 50 tons/sq. in. remained unbroken after 20×10^6 cycles for eleven casts. With the remaining cast, fracture was obtained at less than 10^6 cycles. Therefore, a microradiographic examination was made on this cast and also on three which had improved fatigue properties. The tests showed that spherical inclusions were only present in the cast which gave the low fatigue properties.

Further evidence that the elimination of the non-deformable type of spherical inclusion was beneficial to the fatigue properties of basic electric-arc steel was obtained by remelting this type of steel in a basic H.F. vacuum furnace. Before remelting, the steel contained spherical inclusions, and fracture was obtained after $0{\cdot}97 \times 10^6$ cycles with a reversed bending stress of $\pm$ 50 tons/sq. in. After vacuum remelting and rerolling, these inclusions were not observed, and test pieces from two casts were unbroken after 20×10^6 cycles under the same test conditions.

Microradiographic tests were also carried out on nine casts made in electric-arc, H.F., or O.H., furnaces, by the acid or neutral process. No spherical inclusions were observed in any of these steels, but four casts (test series *HFA* 3, *OA* 7, *ON* 7, *ON* 10) had rather low fatigue properties.

With these 750 D.P.N. steels, fracture frequently occurred below the surface of the critical section, as for the steels heat-treated to 110 tons/sq. in. U.T.S., and these test pieces also had a white circular area on the fracture face. No metallographic examination was carried out on these specimens, but it did appear, as for the lower tensile steels, that the fracture was initiated by an inclusion near the centre of the white area.

As previously stated, the amount of austenite retained during the heat-treatment process, or produced during the final grinding operation, was assessed by magnetic and X-ray diffraction tests. The former test gave a measure of the relative amounts of retained austenite through and along the critical section, whilst the latter test only referred to a small area of about $\frac{1}{4}$ in. $\times$ $\frac{1}{8}$ in. on the surface of the critical section. These tests showed that there was no correlation between the magnetic saturation values or X-ray diffraction test results and the fatigue properties of these C–Cr steels. The critical section of these test pieces was finished by grinding and polishing longitudinally with 00 emery paper, the grinding operation being very carefully controlled for all the specimens. No surface austenite was detected on the surface of the critical section for most of the test pieces, and therefore for the few test pieces which had surface austenite it was assumed that it was retained from the hardening operation and not produced during the grinding operation. It may be that austenite retained on the surface from the hardening operation is not so detrimental to the fatigue properties as surface austenite produced by grinding. This appears to be a possibility, because during the hardening operation the complete critical section is converted to austenite, and then on quenching most of this austenite breaks down with an expansion to martensite. The austenite which remains may therefore be stressed in compression. However, when austenite is formed on the surface by grinding it is produced locally with a contraction, and as the surrounding metal remains stable the austenite is most likely stressed in tension. Evidence that the fatigue properties of steels heat-treated even to 60 tons/sq. in. U.T.S. can be considerably reduced by heavy grinding was obtained by carrying out repeated impact tests on studs. The threads for these studs were produced by cutting with a die, grinding, or rolling, and it was shown that heavy grinding could reduce the fatigue limit at least 40%. The full fatigue properties were restored by a shot-blasting treatment, and it was considered that the low fatigue properties obtained after grinding were due to the formation of surface austenite.

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Bearing Cartridge Bolts for Roller Tables

By Comdr. (E) J. I. T. Green, O.B.E., R.N.(Ret.), M.I.Mech.E., and A. Conway, B.Sc.(Eng.), A.C.G.I.

SYNOPSIS

Overloading of the bolts securing the roller-bearing cartridges in some primary mills has occurred, resulting in repeated failures. The paper reviews some of the possible causes of failure, describes the tests carried out at the Abbey Works of the Steel Company of Wales Ltd., and concludes that short of complete redesign the best solution of the problem is to make provision for very much greater initial tension being put on the bolts than has hitherto been the case. 1081

THE ARRANGEMENT of bolting the bearings of rollers on live tables to the bed has been satisfactory until recently, when, with throughputs exceeding a million tons annually, some of the larger slabbing mills and auxiliaries have been suffering unprecedentedly severe loading. The increase in ingot size and weight, coupled possibly with the effect of tandem rolling, has imposed a particularly severe duty on the main tables of the mill and one result of this has been failure in the bolts anchoring the rollers. Failure has occurred, even in high-tensile bolts, at the first two or three threads near the shank of the bolt. Failure at the junction of shank and tee-head is obviated when relieving grooves and adequate fillet radii have been introduced. These defects have resulted in some cases in faulty meshing of the bevel gears, with consequent heavy wear on the teeth.

It is well known that as dimensions are increased, the stresses caused by moving masses in similar structures will increase and, unless a radical change in design is made, there comes a point where further increases in dimensions will result in failure. Whether or not this is the main cause of the failures of these bearing bolts is a matter for judgment, but the following account may provide some evidence on which to base an opinion.

THEORETICAL CONSIDERATIONS

A proper approach to the subject can only be made by considering the mechanical principles involved. Although these principles are well known it is felt that a brief recapitulation is worth while.

If a bolt holds two mating elements together, the tension force in the bolt and the compression force in the seating are equal. An external load tending to separate the elements will increase the bolt tension and reduce the seating compression. Provided that the external load is applied under the head of the bolt and under the nut, the change of tension in the bolt is given by

$$\Delta F = \frac{W}{1 + K_s/K_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where K_s = stiffness of seating elements

K_b = stiffness of bolt (*see* Appendix I).

The ratio K_s/K_b is an important relationship which largely fixes the behaviour of the fastening under external loads.

Equation (1) is illustrated graphically in Fig. 1, where OB represents the elastic load/extension diagram of the bolt, and OA that of the seating, compression being regarded as negative. With the force F_1 in both bolt and seating the initial condition of the bolt is represented by point P_1. A line P_1M is drawn parallel to OA. The external force W is represented as a vertical between P_1B and P_1M so that the final load on the bolt is given by P_2 and the force on the seating by point Q.

It is evident from the diagram that the additional force on the bolt $F_2—F_1$ depends upon the relative slopes of OB and OA, which are proportional to K_b and K_s, respectively. In particular, if another diagram is drawn with a smaller slope for OB it will readily be seen that $F_2—F_1$ will be smaller for a given value of W.

If W is increased so much that the bolted parts become unseated, the whole force is taken directly on the bolt. The value of this unseating load is obtained by putting $F_2 = W$ and substituting in equation (1). Thus:

$$\text{Unseating load} = \frac{F_1(1 + K_s/K_b)}{K_s/K_b} = F_1(1 + K_b/K_s) \ldots (2)$$

This condition is represented in Fig. 1 by P_3M; provided that W does not exceed this figure, the

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Mr. Conway is on the staff of the Association's Mechanical Engineering Section, of which Comdr. Green is Head.

fluctuating load cannot exceed that given by equation (1), and the minimum tightening load required to sustain a given maximum external load without unseating is

$$F_1 = \frac{W_{max}}{1 + K_b/K_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Conditions under Impact Loading

When a load is suddenly applied to a bolt it must absorb and help to dissipate the energy lost by the moving mass in being brought to rest. The energy of the resulting vibration is eventually dissipated in the form of heat. The fluctuation in stress for a given shock is smaller in a more resilient or less stiff bolt (*see* Appendix II).

Stress Concentrations

It is well known that the effect of notches, grooves, holes, etc., is to cause localized stresses in excess of the nominal stress across the section. The ratio of the maximum local stress to the nominal stress, which is known as the 'stress-concentration factor,' increases with the sharpness of the discontinuity. It is found that fatigue failure does not occur as early as the stress-concentration factor would lead one to expect, although the experimentally determined ratio approaches the predicted value as the size of the component increases.[1] Useful design factors can be estimated with the help of these concentration factors.[2]

Screw threads are, of course, a location of stress concentrations. Quite apart from the notch effect, the stress distribution along the engaged length of a conventional thread cannot be uniform (*see* Fig. 2). The latter effect can be made less serious by using special forms of nut which distribute the load more evenly, and the notch effect can be minimized by specifying a thread of suitable form and pitch.

Complete treatment of what is known about the general question of fatigue of large bolts is to be found in the standard works, attention being particularly drawn to the contributions of the British Shipbuilding Research Association.[3]

Loss of Pre-Tension in Service

Loss of pre-tension is due principally to the plastic yielding of peaks of surface roughness, both at the screw threads and at all surfaces in contact. The settling-down process starts as soon as the bolts are put in service and loss of tension may occur in the first ten load cycles.[4] Since for identical seatings and pre-load a more resilient bolt will suffer a smaller fluctuating load, it maintains its pre-load more satisfactorily than a conventional full-shanked bolt. Loss of pre-tension also occurs when the external loading causes local concentration of stress above the yield point.

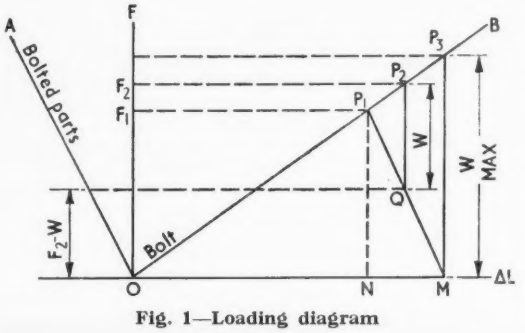

Fig. 1—Loading diagram

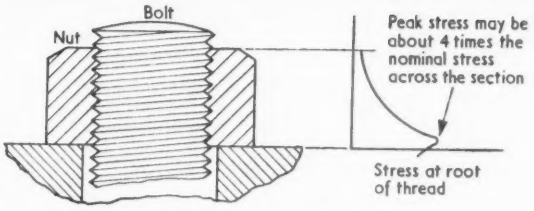

Fig. 2—Stress distribution on thread

Summary of Design Requirements for Large Bolts

The essentials of good design can be summarized as follows:

(i) The seatings must be as rigid as possible

(ii) The bolts must be capable of taking a pre-load sufficient to ensure that there will be no unseating under shock loads. For very heavy pre-loads, the combined stresses due to tension and torsion on tightening may approach the yield point, and this sets a limit on what can be done with a conventional design of bolt and nut

(iii) To provide adequate resilience in the bolt the shank area must be less than the core area of the threaded portion

(iv) The bolt details must be such that stress raisers are reduced to the minimum, and the material must be chosen for its resistance to fatigue and freedom from notch brittleness

(v) The number of mating surfaces should be kept to the minimum.

TESTS AT THE STEEL COMPANY OF WALES

In view of the frequency of bolt failures on the roller table serving the 45-in. slabbing mill at the Steel Company of Wales Ltd., Port Talbot, tests have been carried out in collaboration with the Research Department of Davy and United Engineering Co., Ltd., to measure the loads borne at two of the more vulnerable positions on the table. It was not possible to fit strain gauges to the bolts without some modification in their design, and advantage was taken of this to make use, in one case, of a design of load-distributing nut with a partially hollowed-out bolt. The bearing housing or 'cartridge' had also to be slightly modified to take the special measuring bolts and Fig. 3 shows the details of installation.

Bolt *A* and its nut (on the right) is of the normal type, apart from the necessary modifications referred to, whilst bolt *B* and its nut was adapted from a design recommended by Sopwith.[5]

A pair of strain-gauge bridges was mounted on each of the bolts and they were calibrated in the laboratory before the tests. When the bolts were

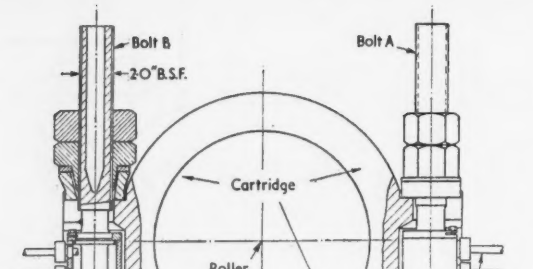

Fig. 3—Roller-bearing cartridge (reproduced by permission of Davy and United Engineering Co., Ltd.)

under static pre-load only, the bridge outputs were measured on a vernier potentiometer to determine the value of the pre-tensions. For recording service loads the bridge outputs were received on a cathode-ray oscilloscope and photographic oscillograms were taken during normal mill operation over a reasonable period of time.

The nuts were tightened by application of a sledge-hammer to the spanner, the criterion of sufficient tightness being the ' feel.' The ' locknuts ' were not tightened in the usual way for locking purposes, but were merely screwed down hard on the primary nuts. As soon as the pre-loads were measured it was clear that the design of bolt *B* had a marked effect on the pre-load which could be imposed by this means. This is evidently due to the more even spreading of the applied force over a greater length of screw thread. The pre-tensions in the two bolts decreased with time, however, as shown in Table I.

The method of observation and recording was as follows. The events during the slabbing process were classified (e.g. ' turn over to flat,' ' pass in,' ' pass out,' etc.) and identification letters were allotted to them. Three observers worked simultaneously—one operating the camera on the C.R.O., another noting the class of event occurring during the action of the camera, and the third noting the serial number of the pass for the particular ingot. About 150 events were oscillographed.

A typical oscillogram is shown in Fig. 4. There are three traces, one for each bolt and one for the time-marker. The traces for the two bolts appear to differ in quality because the amplification used on the two channels was different. This was necessary because the order of magnitude of the variable part of the load was different for the two bolts.

The nature of the variation also differs in the two cases. In the special bolt there is a damped oscillation about the mean load, which is the pre-tension, whilst in the normal bolt there is no such oscillation about the mean, but only a varying increase in the load above zero. The scale of the normal bolt

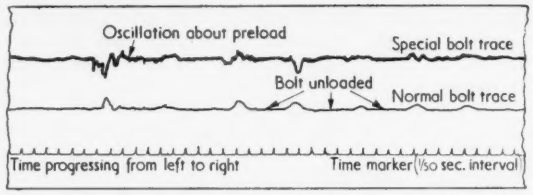

Fig. 4—Typical oscillograph diagram. Vertical movements of the bolt traces represent changes of load. The axis of origin of the load ordinates is not shown

trace is such that the small pre-tension cannot be detected.

Ingots of 7, 10, 12, 14 and 15 tons were rolled during the period of observation, sometimes in tandem. Table II shows the highest maximum loads found in the records in association with each weight of ingot. The upward trend is marked in the case of the normal bolt but is scarcely noticeable in the case of the special bolt.

Tables I and II make it clear that the variation of load in the normal bolt was much greater than that in the special one.

The tests were made to determine the maximum loads experienced in service rather than to establish the exact mechanism of their incidence and variation, and it is not possible to draw any statistical inferences from the results. It appears, however, that the highest loads tend to occur earlier in the rolling sequence, and that the operations producing the severest loads are those in which the stock is ejected from the work rolls (regardless of the orientation of the section) and those in which it is turned over to the flat by the tilters.

DISCUSSION

The theoretical importance of the relative stiffness of the bolts and the seatings has been shown for the simplest case, and it might appear at first sight that the method of securing the cartridge by bolting down on lugs would yield a different result. As shown in Fig. 3, the cartridge is seated centrally on its base, and there is a clearance between the side lug and the bedplate.

When the two bolts are tightened the cantilever lugs are deflected and the bolts stretched. When a sudden downward load is applied to the cartridge the

Table I

PRE-TENSIONS OF TEST BOLTS

Day	Time	Pre-load, tons	
		Normal Bolt (*A*)	Special Bolt (*B*)
1	Evening	8·00	33·4
2	11.00	4·02	26·4
2	18.00	3·29	25·7
3	11.00	1·84	25·0
4	11.00	0·69	23·7

reflected stress wave can cause a vertical up-load on the bolts. Alternatively, the cartridge can be tilted with the same effect. The lugs do not contribute to the stiffness of the seating itself, but act rather as very stiff spring washers under the nuts.

It might appear from this that bolting down on cantilever lugs is superior to bolting down on directly seated lugs, since it reduces the effective stiffness of the bolt. In practice, however, the cantilever lug must bend and so exert a non-uniform load over the contact area of the nut, resulting in still greater stress concentrations in the bolt. To minimize this effect the lug must be made so stiff as to destroy its advantage, and on balance the method may be less satisfactory than direct seating.

The use of spring washers to reduce the effective stiffness of the bolt might appear desirable as an alternative to the use of lugs, but in practice the type of washer that can be fitted merely encourages the loss of pre-tension.

In regard to the general question of pre-loading, this is a problem which crops up in many branches of engineering. An example may be quoted of the owner of a sports car who had some difficulty in refitting his engine. He had to apply to the manufacturers for instructions regarding the tightening of the connecting-rod ' big-end ' bolts. In reply they sent him a double supply of bolts and told him to practise tightening until he knew how far to go just short of breaking them. This is an extreme example of maximum pre-load on a relatively flexible bolt giving minimum fluctuating load.

CONCLUSIONS

It appears probable that the main cause of failure of these bolts is the lack of pre-tension. The heavy loads experienced in the normal bolt were many times the value of the pre-load, which shows that unseating of the cartridge has occurred.

Although there is no guarantee that the special bolt was subject to exactly the same loading conditions as the normal one, the evidence confirms that with a substantial pre-tension the additional shock load is very much reduced.

The bolts originally fitted have been replaced by bolts designed to withstand dynamic loads, and this has resulted in some alleviation of the trouble, but the use of a special rig for hydraulic pre-loading without twisting, as designed by the Steel Company of Wales Ltd., will provide a more complete solution. The rig is illustrated diagrammatically in Fig. 5. Another method was described by Leufvén.[6]

The need for easy removal and replacement of the roller-bearing cartridges is appreciated, but it is strongly recommended that in any future design the method of bolting down should be revised to allow a uniform loading over the annular contact area of the nut. The elimination of washers is a desirable objective.

Table II

HIGHEST MAXIMUM LOADS ON TEST BOLTS

Ingot Weight, tons	Highest Maximum Load, tons	
	Normal Bolt (*A*)	Special Bolt (*B*)
15	62·3	31·0
14	40·0	30·7
12	18·9	28·1
10	26·8	28·7
7	17·8	29·6

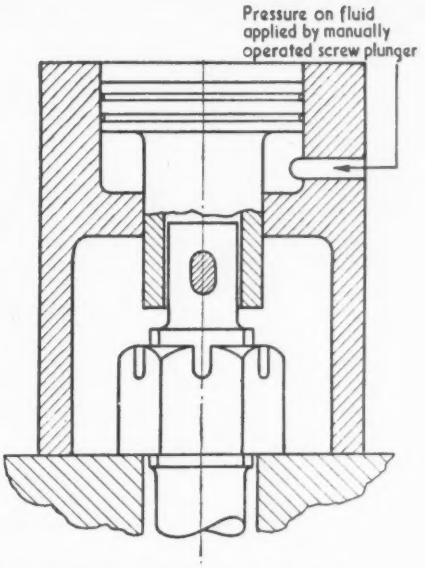

Fig. 5—Schematic diagram of a hydraulic pre-loading device for heavy bolts

Acknowledgments

These trials were conducted by Mr. R. B. Sims, Research Manager of the Davy United Engineering Co., Ltd., in collaboration with B.I.S.R.A., and acknowledgments are due to the Company for permission to reproduce details of their experiments.

Acknowledgments are also due to the Steel Company of Wales, Ltd., for their collaboration and encouragement and for permission to describe the bolt pre-loading device.

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APPENDIX I

For any elastic material

$$E = FL/A.\Delta L$$

where E = Young's modulus
F = Total load on the section
A = Area of cross-section
ΔL = Change of length

The ' stiffness ' of a member is defined as the force per unit extension, given by

$$K = F/\Delta L = EA/L$$

so that

$$\Delta L_b = F_1/K_b \text{ and } \Delta L_s = F_1/K_s$$

where subscripts s and b refer to ' seating ' and ' bolt,' respectively, and where F_1 is the tension in the bolt before applying the external load W.

Since in general the stiffness of the seating will not be the same as that of the bolt shank, the amount of compression of the former is not the same as the amount of extension of the latter.

After applying the load W there is an increase of tension in the bolt, say to F_2:

New extension in bolt	$= F_2/K_b$
Increase in extension	$= (F_2 - F_1)/K_b$
Force of compression on seating	$= F_2 - W$
New compression of seating	$= (F_2 - W)/K_s$
Reduction in compression	$= (F_1 - F_2 + W)/K_s$

Thus the seatings have expanded as a result of exerting the force W under the bolt head and nut, and this movement must be the same as the additional extension in the bolt; hence, equating these quantities gives

$$(F_2 - F_1)/K_b = (F_1 - F_2 + W)/K_s$$

Putting

$$\Delta F = F_2 - F_1$$

$$(K_s/K_b)\Delta F = W - \Delta F$$

whence

$$\Delta F = \frac{W}{1 + K_s/K_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

APPENDIX II

Appendix I shows that the equivalent stiffness of the system of bolt and seating is that of two elastic bodies in parallel. Thus combined stiffness is given by

$$K = W/\text{change of length}$$
$$= \Delta F(1 + K_s/K_b)K_b/\Delta F = K_b + K_s$$

If the separating force is suddenly applied, e.g. by a moving mass, its maximum value depends both on the stiffness of the assembly and on the mechanical energy imparted by the retarded body. Suppose the value of this energy to be U, represented by the area P_1P_2Q in Fig. 1; then

$$W_{\max} = \sqrt{[2U(K_b + K_s)]}$$

and equation (1) becomes

$$\Delta F = \sqrt{\frac{2UK_b}{1 + K_s/K_b}}$$

This equation is useful when it is possible to estimate the energy actually applied to and absorbed by the bolted connection. It illustrates also that the fluctuation in stress due to a suddenly applied load is less with a resilient bolt than with a stiff bolt. This can also be verified from Fig. 1.

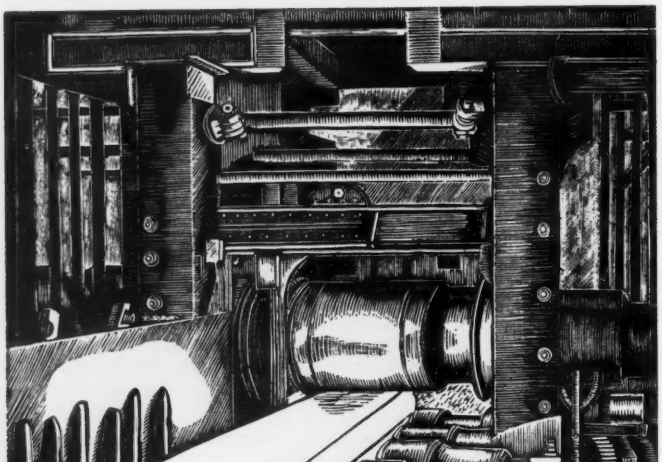
In the simple case of a bolt suffering a tensile shock and storing a maximum energy U_b,

$$U_b = F^2/2K_b = F^2L/2AE = f^2AL/2E$$

If the bolt is made up of a number of lengths L_1, L_2, L_3 of unequal section areas A_1, A_2, A_3, it is easily shown that, if A_1 is the smallest,

$$U_b = \frac{f_1^2A_1}{2E}\left(L_1 + \frac{A_1}{A_2}L_2 + \frac{A_1}{A_3}L_3\right) < \frac{f_1^2A_1}{2E}\left(L_1 + L_2 + L_3\right)$$

This illustrates the weakness of having a very short length of the smallest diameter such as would occur in a simple ' black ' bolt having no ' stretching length.'



Rolling a slab from a steel ingot

(From the original woodcut by Viva Talbot)

Joint Spring Meeting of the Institute of Metals with the Société Française de Métallurgie 1954

The 1954 Spring Meeting of the Institute of Metals was held in London jointly with the Société Française de Métallurgie from Monday to Friday, 26th to 30th April. Members of The Iron and Steel Institute were invited to attend the meeting on the same basis as members of the Institute of Metals.

Scientific Session " C " was held in the Bishop Partridge Hall, Church House, London, S.W.1, on Wednesday, 28th April, 1954, at 10 A.M. Papers on the diffusion of nitrogen in iron and the continuous cooling of steel were presented and discussed; a report of this discussion appeared in the April issue.

At an Additional Session " C," held on the same day and with Professor G. L. Chaudron in the chair, the following paper was presented and discussed; the discussion is printed at the end of the paper.

Kinetics of the Martensite Transformation in a Hyper-Eutectoid Steel

By J. Philibert and C. Crussard

SYNOPSIS

The decomposition behaviour at sub-zero temperatures of a 1·4% C, 2·5% Cr steel initially quenched to 20° C. has been investigated. By direct cooling to low temperatures ($\leqslant 0°$ C.), martensite forms on cooling but an additional isothermal increment can be observed at the holding temperature; its extent depends on the temperature concerned. On the other hand, by quenching in suitable stages, followed by stabilization, it is possible to eliminate all transformation during cooling, and thus record purely isothermal transformations associated with an incubation time which may exceed 5 min.

From the results it seems that there is no ' athermal ' nucleation of martensite, but rather a classical type of random nucleation caused by thermal changes; the apparently athermal character of the martensitic transformation is explained then by the particularly high rate of nucleation in the region M_S–M_f. Theoretical calculations allow this high rate of nucleation to be taken into account satisfactorily. 1036B

Introduction

ALTHOUGH numerous studies, both theoretical and practical, have been devoted to martensitic transformation, many points are not yet clear and some fundamental questions have not yet received a satisfactory answer. Quite apart from discussions on the crystallographic mechanism of the change from f.c.c. to b.c.c. lattice, the kinetic and thermodynamic problems have been greatly affected by the discovery in some alloys of an ' isothermal ' transformation forming a continuation to the classical ' athermal ' transformation; and yet this characteristic of ' athermality ' used to be considered as absolutely fundamental, an essential consideration even before one

Manuscript received 25th March, 1954.

Professor Crussard is Head of the Department of Physics of the Institut de Recherches de la Sidérurgie and Mr. Philibert is a member of the staff.

could think of understanding martensitic transformation.*

Consequently, in face of this evidence, theories now speak of two 'modes of nucleation' in order to take into account these two components of transformation. Thus Cohen, Machlin, and Paranjpe[1] conceive deformation embryos or 'centres of distortion' in the γ lattice. These embryos are 'activated,' either by lowering the temperature—which reduces the critical nucleus size—or by thermal fluctuations[2] contributing the extra energy necessary for the embryo to become a nucleus at a given temperature.†

These two mechanisms have the advantage of being very similar, making it easy to visualize why identical products are obtained from transformation. However, Fisher, Hollomon, and Turnbull[3] suggest such radically different modes of nucleation that it is difficult to conceive how identical end-products can arise. Athermal martensite is considered to be nucleated by regions impoverished in carbon (by fluctuations of local composition at austenitizing temperature) and retained during the quench. Isothermal nucleation on the other hand would simply be due to fluctuations of free enthalpy at the transformation temperature. However, Fisher[4] has suggested that nucleation in ferro-nickels is always produced in the isothermal mode, and the rates of nucleation, depending on composition and temperature, will be either very high and not measurable or else slow enough for the transformation to be recorded (at a fixed temperature). Fisher also states, however, that the nucleation in carbon steels must be athermal and due to fluctuations in composition.

It is therefore of considerable interest to study the martensitic transformation of carbon steels with an M_s point nearer that of alloys with $M_s < 0°$ C. whose transformation is isothermal; and to study it in a temperature zone lower than that generally studied (where the transformation seems to be purely athermal‡). This has led us to choose a hyper-eutectoid steel whose M_s point is slightly higher than room temperature; the same steel on which the stabilization of austenite had previously been studied by Plateau, Duflot, and Crussard.[5] While studying the variations of thermo-electric power as a function of the amount of martensite formed by cooling below room temperature, it has been noted that an isothermal transformation seems to appear in certain cases. This phenomenon has been studied by various means: it is generally quite weak, but in particular conditions it can become important and may even be the only one manifested.

These results are discussed in the light of present theories and some new hypotheses which take into account not only the results presented here but also certain facts indicated in some recent publications.

EXPERIMENTAL PROCEDURES

Thermal Treatments

The martensitic transformation studied is that of a chromium hyper-eutectoid steel whose composition, wt.-%, is as follows:

C	Si	Mn	S	P	As
1·43	0·213	0·22	0·013	0·020	0·033

Ni	Cr	Cu	Mo	V
0·11	2·55	0·050	0·008	0·015

The test pieces used were generally 3-mm. dia. cylinders. For thermo-electric measurements the specimens should be quite long (90 mm.); for dilatometric tests a length of 50 mm. is sufficient.

Austenitization was done for 1 hr. at 1095° C., in an atmosphere of dry argon with a pressure of 1 atm.; this treatment was followed by a water quench to room temperature. Specimens thus obtained are slightly martensitic (about 3–4% of martensite), the M_s point being slightly above room temperature, which is 18–19° C. By extrapolation it can be placed at about 25° C. The measurement of thermo-electric power also provides a practical means of controlling specimens after quench.

Holding at low temperatures was assured by using a Dewar flask filled with an appropriate organic liquid, cooled by the controlled admission of liquid nitrogen; by vigorous movement the homogeneity of the temperature can be ensured to well within $\frac{1}{4}$° C. To retain this degree of temperature control and reduce the time for attaining bath temperature it is advisable to work with quite short, thin samples.

Methods of Measurement

Thermo-electric Power—The method described by Crussard and Aubertin[6] for cylindrical specimens was used. For all measurements, three reference test pieces (Al, Cu, Fe) were used successively. This allows constant control of the measurements. The average error in these conditions was less than 0·1 μV./° C., equivalent to less than 1% of martensite. For thermal reasons, a test piece 90 mm. long is necessary; otherwise the heat from the hot junction does not flow into the atmosphere and begins to heat the cold junction. For the same reasons, a temperature difference of 5° C. between the hot and cold junctions should not be exceeded.

Dilatometry—The recordings were made on the IRSID isothermal dilatometer. The specimen was extended by two prongs which allow it to be fixed to the connecting rods; there was no reference specimen, so absolute dilatations were recorded. The holding times were variable, never more than $\frac{1}{2}$ hr. The time to attain bath temperature was determined by the dilatometric testing of a previously transformed test piece. It varied almost linearly with the temperature and was strongly influenced by the diameter of the specimen and by the liquid used. Several ranges of cooling rates were thus available. In methyl alcohol

* If thermal fluctuations contribute partially or totally to the nucleation mechanism, the reaction can be considered as a series of 'isothermal steps,' whereas if thermal fluctuations are not involved, the nucleation process must be considered truly athermal. The word 'anisothermal' will also be used in a purely experimental way meaning that martensite is formed during the time that the temperature of the sample is changing, without taking the mode of nucleation into account.

† An embryo may be regarded as an assemblage of atoms having the required crystallographic arrangement and composition to transform into a new phase but leading to an increase in free enthalpy through growth. An embryo becomes a nucleus when its size is such that the free enthalpy decreases on further growth.

‡ The majority of kinetic studies on carbon steels have been carried out on alloys with < 1% C and M_s points of 250–450° C.

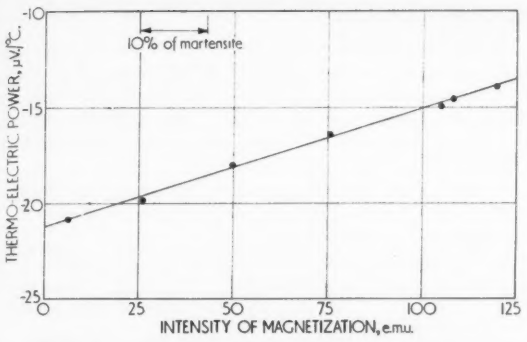


Fig. 1—Relationship between the thermo-electric power (measured relative to a standard iron specimen) and the intensity of magnetization at saturation measured on a small piece taken from the thermo-electric power specimen

the time to reach bath temperature was some tens of seconds, but in *iso*pentane it was always less than 15 sec., even at very low temperatures. In what follows it will be given the symbol τ_0.

Measurement of Intensity of Magnetization—The measurement of magnetic intensity at saturation (at room temperature) yields a value which varies linearly with the percentage of martensite. These measurements have been determined by Professor Guillaud at his Bellevue Laboratory. This is also the best way of calibrating, in values obviously only relative, the dilatometric and thermo-electric methods of measurement.

Comparison of These Three Methods—Thermo-electric power was measured for a whole series of dilatometric test pieces, then each one was cut into several small pieces 5 mm. long for the magnetization measurements. As the test pieces were long these small pieces were taken from the middle and the ends, allowing a check on the homogeneity of transformation. Deviations from the values obtained in the centre were evident within 10 mm. from the ends. For well homogenized specimens, as can be seen in

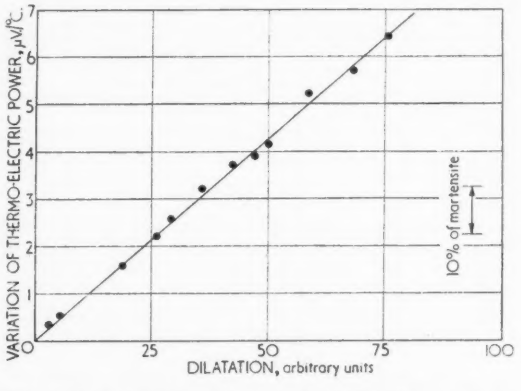


Fig. 2—Relationship between the dilatation and the variation of thermo-electric power measured on the same specimens as Fig. 1

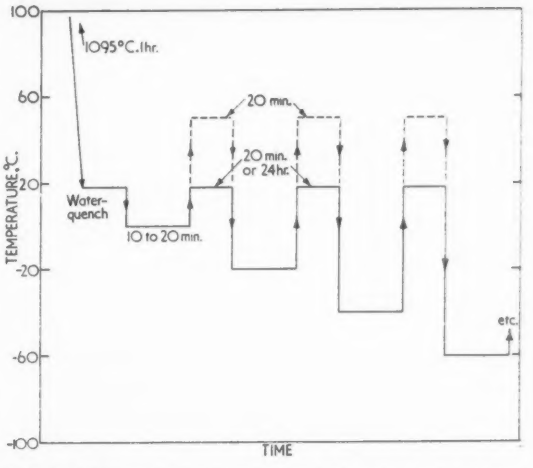


Fig. 3—Thermal treatments used showing cooling and stabilization holding times

Figs. 1 and 2, the thermo-electric power, like the dilatations, varies linearly with the intensity of magnetization at saturation.

Thus the thermo-electric power varies linearly with the quantity of martensite. A convenient procedure then is available for determining the state of a specimen, in this case the state of a specimen after quench. This allows the progress of transformation to be easily followed. The method is quite rapid and sure, and escapes the inconveniences of resistance measurements for example. Unfortunately, it requires rather long specimens and also does not permit isothermal transformations to be recorded.

As stabilization of the austenite occurs very quickly in the steel studied, totally martensitic specimens cannot be obtained. (It will be seen that by quenching in liquid nitrogen rather less martensite is obtained than at $-100°$ C.) For this reason the magnetic method does not provide a means of absolute calibration.

Micrographic Study—Absolute calibration is only possible by micrography. However, this is not more accurate than to within 2%. Many needles have a jagged appearance, others have a featherlike structure, making it difficult to estimate the quantity of martensite present.

This quantity is therefore determined by lineal analysis. The calculations have been carried out on micrographs taken longitudinally and transversely on the specimen, and in several directions in each case. The formation of 10% of martensite is manifested by a variation in the intensity of magnetization of 18 e.m.u. and by a variation in thermo-electric power of 1·08μV./° C. For 3-mm. dia. specimens, the maximum quantity of martensite obtained by cooling to $-100°$ C. does not reach 70%. On the other hand, for 1·5-mm. dia. samples, the transformation is practically complete under the same conditions.

EXPERIMENTAL RESULTS

The treatments undergone by the specimens, after quench, were of two types:

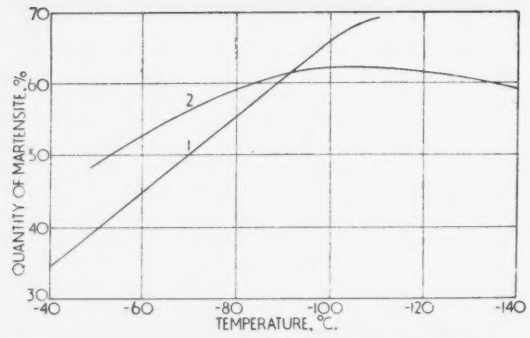


Fig. 4—Transformation curves obtained with different rates of cooling, showing (left) normal, (right) inverse stabilization. (1) Slow cooling in alcohol at 2–3° C./sec.; (2) rapid cooling in *iso*pentane at 8–10° C./sec.

(*a*) Each specimen was brought directly to a fixed holding temperature, and one specimen was therefore used for each measurement

(*b*) Each specimen was cooled in stages: it was (i) quenched into a bath at 0° C., (ii) raised to room temperature (or slightly higher, either 50° C. or 70° C.), then (iii) brought again to a temperature below 0° C. (20° C. lower each time) and so on, as shown in Fig. 3.

Direct Cooling

Several series of specimens were used, each undergoing only one cooling. The results are very reproducible; e.g. for the measurements of thermo-electric power, the variation between different specimens which had undergone the same treatment remained less than the average error determined by the measurements made with the three reference samples. The holding time at the temperatures indicated was 10 min.

It is interesting to compare the transformation curves obtained with very rapid cooling, in *iso*pentane, and with slower cooling, in alcohol. With alcohol a straight line was obtained down to — 100° C.; with *iso*pentane, however, the transformation was more marked down to — 80° C., but after that the curve flattened so that at — 100° C. less martensite was present than with slower cooling, i.e. the quantities obtained at lower temperatures were progressively smaller.

Therefore, as well as the phenomenon of normal stabilization (a less marked transformation in slower cooling) there was an effect of inverse stabilization[5]: a less marked transformation corresponding to a more rapid rate of cooling. All this is easily understood by assuming an isothermal nucleation, as two opposing factors enter into consideration:

(i) The time at each temperature and in each temperature range
(ii) The effect of normal stabilization.

Furthermore, the weakening of the transformation noted for quenches to very low temperatures showed that the temperature range where the rates of transformation are considerable had been crossed rapidly. It will be shown later how the variation in rate of transformation with temperature can be predicted.

Isothermal Recordings

This series of dilatometric investigations was carried out under the same conditions as the series of experiments just described. A slight isothermal transformation was observed to follow the transformation occurring during the cooling period τ_0. The course of the transformation is as follows:

(i) At 0° C., where τ_0 is very small, about two-thirds of the transformation occurs between τ_0 and the end of the first minute
(ii) At — 20°, — 40°, and — 60° C., the isotherma increment is little more than a tenth of the total transformation and extends for some tens of seconds
(iii) At — 80° C., the isothermal increment is equally important but it lasts for 3 min.
(iv) From — 100° C. downwards, the anisothermal transformation decreases slowly and the isothermal increment extends for 5 min. or more.

The isothermal increment is quite weak; but it does not give a true idea of the rates of nucleation since it follows a marked transformation and stabilization. To determine these rates, a careful study of the dilatometric curve must be made; as Fig. 5 shows, it can be divided up as follows:

(i) a contraction; the unavoidable contraction due to the cooling outweighing the expansion due to transformation
(ii) a dilatation; the opposite of (i)
(iii) a new contraction at very low temperatures (from — 140° C. downwards), when the rate of transformation has slowed up enough for the thermal contraction to prevail again
(iv) a new dilatation (due to isothermal increment) when the holding temperature has been reached. At — 195° C., however, this last part is not observed, because the M_f point has been passed.*

By taking very rapid dilatometric readings, during which stabilization is at a minimum, it was possible to determine the critical points where the dilatation changes sign: the values of rates of isothermal transformation at certain temperatures were thus obtained (Fig. 6). The total amount of martensite obtained thus allowed an approximate determination of the maximum of the transformation-rate/temperature

* The M_f has a significance symmetrically opposite to that of M_s: it is the temperature below which the rate of transformation is nil.

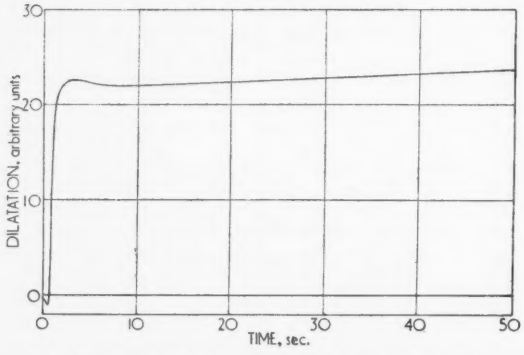


Fig. 5—Dilatometric recording observed on a specimen brought from room temperature to — 140° C., showing three turning points corresponding to the intersections of the two curves of Fig. 6

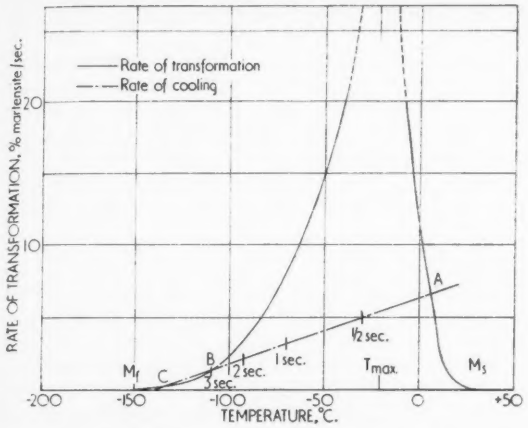


Fig. 6—Variation of the rate of transformation with temperature, showing definition of M_s, T_{max}, and M_f. Comparison with curve representing the rate of cooling *v.* temperature. Points A, B, and C correspond to temperatures where the variations of length of specimen in relation to time pass through a turning point.

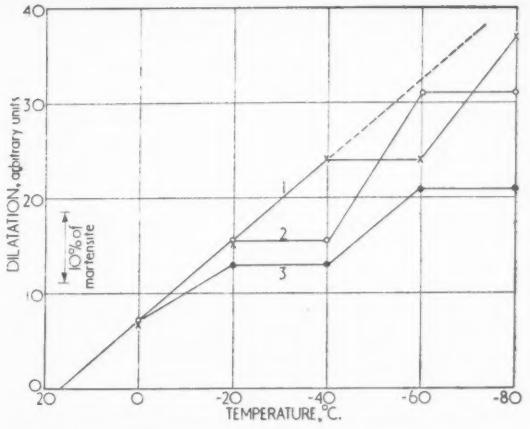


Fig. 8—Transformation curves of specimens held, between each cooling cycle, for 20 min. at (1) room temperature, (2) 50° C., and (3) 70° C.

curve. This presents a very steep slope towards M_s, a very sharp maximum, then a curve falling away hyperbolically.

Cyclic Cooling

Different cyclic treatments were carried out on 50-mm. specimens. Between each sub-zero holding treatment, stabilization was carried out either by holding at room temperature (20 min. or 24 hr.) or by holding at 50° C. or 70° C., as shown in Fig. 3.

Transformation/Temperature Curves

The specimen stabilized by holding at room temperature for 24 hr. was transformed a little less than that held for only 20 min. In all cases the transformation curve for cooling in 20° C. increments had a horizontal portion between — 40° C. and — 60° C. (no transformation at — 60° C.), and a sharp rise again at — 80° C. At this temperature the quantity of martensite formed was particularly striking since between — 60° and — 80° C. the specimen was again raised to room temperature for a further stabilizing treatment. If the first part of the curve, i.e. that which precedes the flat portion, is extended, the curve shown dotted is obtained (Fig. 7). The point corresponding to — 80° C. is only just below this curve: stabilization is therefore temporary, and catches up very quickly.[5] Similar phenomena followed: at — 100° C. again further transformation was absent.

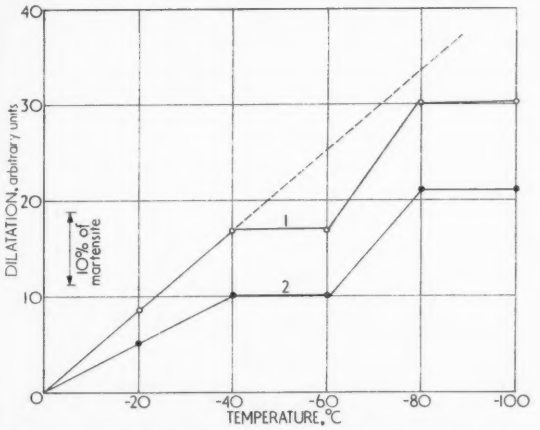


Fig. 7—Transformation curves of specimens held, between each cooling cycle, at room temperature for (1) 20 min., (2) 24 hr., the treatment following the sequence shown in Fig. 3

The behaviour was different on stabilizing by holding above room temperature. There was no transformation at — 40° C. On the other hand, a new stabilization by holding at 50° C. did not prevent the transformation from appearing at — 60° C., where a particularly noticeable transformation was observed, and the transformation curve almost rejoined the dotted curve. In this case the same phenomena as were observed at — 60° C. and — 80° C. with stabilization at room temperature were observed at — 40° C. and — 60° C., i.e. displaced by 20° C. However, by stabilization at 70° C., instead of at 50° C., the extent of transformation at — 60° C. was halved, as is shown in Fig. 8.

These results showing the role of temperature and time of stabilization are well in keeping with what was known of the stabilization phenomenon. Note, however, that in the present case stabilization is not permanent. Reaction is practically normal 40° C. below the temperature at which it is retarded. But it will be shown that this is only possible by extended holding time at the temperature at which the transformation begins again. This fact is demonstrated by studying the dilatometric curves.

Kinetics of the Transformation

The study of the isothermal curves leads us to the fundamental conclusion: in all cases cited in the three

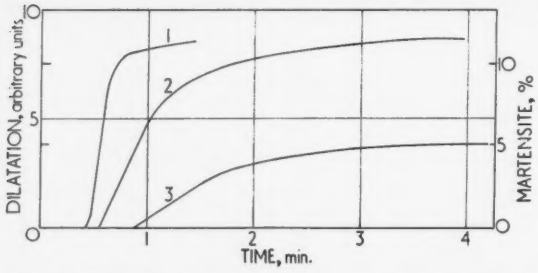


Fig. 9—Isothermal transformation in the region of −40° C. of specimens having undergone successive coolings at 0°, − 20°, and (1) − 42°, (2) − 40°, (3) − 38° C., held for 20 min. at room temperature between each cooling ($\tau_0 = 25$ sec.)

preceding paragraphs, there is no athermal transformation but only isothermal transformations are observed.

At 0° C. or at − 20° C., still only one-half or two-thirds of the transformation was observed after τ_0. Nevertheless the curves, on extrapolation, cut the time axis almost midway between the start and τ_0. It was thus by no means certain that this anisothermal martensite (formed before τ_0) was of athermal formation: on the contrary it is possible that the whole transformation may have taken place by isothermal nucleation.

What was possible at 0° C. or at − 20° C. took place at lower temperatures. From − 40° C. downwards, the isothermal reaction always started after a period $t_0 \geqslant \tau_0$. Figure 9 shows the isothermals obtained during the cyclic cooling with holding times of 20 min. at room temperature. The − 40° C. isothermal started off a little after τ_0, the rate of transformation remaining constant for about 30 sec., before slackening about 20 sec. later to become very slow; the transformation continued for more than 5 min.

On the other hand, with a temperature slightly lower than − 40° C., i.e. about − 41° C., the transformation, which always begins at τ_0, became very rapid and was over in less than 20 sec. Inversely, when holding a little above − 40° C. (i.e. about − 38° or − 39° C.) the transformation was considerably slower; its beginning was not revealed till 30 sec. after τ_0, and it was spread out over about 10 min. The quantity formed was slightly less than that which appeared at − 40° C. Lastly, at − 35° C. and − 37° C. no transformation was observed.

Thus the temperature to which the specimen must be brought back, after transformation at − 20° C. followed by stabilization holding at room temperature, is well defined and the conditions for resumption of the transformation are quite critical.

Similar phenomena were observed at about − 60° C., the conditions being equally stringent. It has been seen that the specimen stabilized by holding at room temperature is not transformed at − 60° C. It must be brought to − 62° or − 63° C. to observe a transformation which begins a little after τ_0 and lasts for a long time, i.e. about 5 min.

Lastly, at − 80° C. the rate of transformation was generally quite slow, and the total duration very long: a large quantity of martensite was formed (Fig. 10). Stabilizing at 50° C. after cooling to − 40° C. did not give any transformation at − 60° C.: transformation resumed at − 80° C. and remained less marked than in the preceding case; furthermore, the transformation did not begin till more than 1½ min. after τ_0, i.e. more than 2 min. after introduction into the cooling bath. The transformation was slow and was not over till about the 18th minute, i.e. it extended for 16 min.

The phenomenon was even more evident at lower temperatures. Firstly, the influence of stabilization on transformation at − 100° C. was observed. The 'deformation' of the transformation curve with increasing stabilizations can be seen in Fig. 11, the incubation period varying from 1 min. to more than 2 min. Secondly, the resumption of transformation ($M'_s \sim -90°$ C.) was observed after stabilization by holding ½ hr. at room temperature following a quench at − 60° C. At − 80° C. there was no transformation; at − 90° C. it began slowly after 5 min. of incubation and was not ended 15 min. later; at − 95° C., the incubation was reduced to 2 min., the rate became much more rapid, and the transformation was completed sooner. The effect seemed less critical than at − 40° C., because in this temperature zone the rate varies much more slowly with temperature (Fig. 12).

Summary

(1) The stringent conditions for the resumption of transformation after stabilization allow the definition of the temperature of resumption by points M'_s. The principal characteristics of these reactions can only be obtained by studying the isothermal transformation records. At M'_s the transformation begins sooner or later after τ_0, when thermal equilibrium with the holding bath is reached. At temperatures below M'_s, the beginning of the transformation becomes more and more distinct, the incubation time becomes shorter, the initial rate of transformation greater, and at still lower the transformation is completed very rapidly (cf. Figs. 9 and 12).

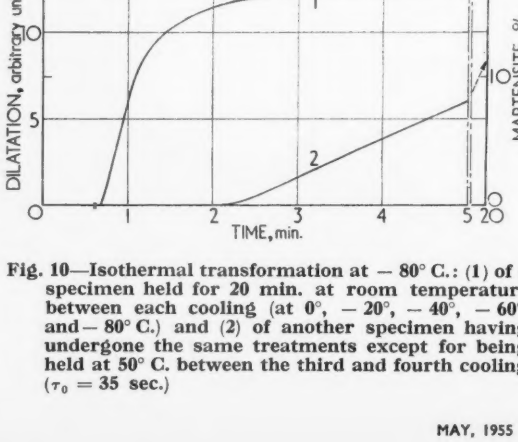


Fig. 10—Isothermal transformation at − 80° C.: (1) of a specimen held for 20 min. at room temperature between each cooling (at 0°, − 20°, − 40°, − 60°, and − 80° C.) and (2) of another specimen having undergone the same treatments except for being held at 50° C. between the third and fourth cooling ($\tau_0 = 35$ sec.)

(2) The stronger the stabilization, induced by longer holding times or by higher temperatures (50° C. or 70° C.), the more difficult are the resumption conditions of the transformation, all other things equal; i.e. a stronger stabilization lowers the M'_s point, by decreasing the rate of transformation and increasing the incubation time (cf. Figs. 10 and 11).

(3) The transformation-rate/temperature curve increases abruptly below M_s (25° C.), passes a very sharp maximum at $T_{max} \sim -20°$ C., then decreases more slowly to become nil at about − 150° C. (Fig. 6).

(4) The influence of rate of cooling on specimens quenched directly depends on the effect of two opposing factors, direct stabilization and inverse stabilization, according to the temperatures chosen (Fig. 4).

DISCUSSION

These results may appear quite disconcerting in the light of the conventional theories, which consider two modes of nucleation for martensite. Here in fact not only exact relationships between stabilization and transformation (or more precisely rate of transformation) are noted, but also only isothermal transformations are observed; i.e. to adopt, provisionally, the conventional terms, the athermal component has been suppressed leaving only the isothermal component.

From the characteristics of the two modes of nucleation generally put forward, viz. in the theories of Cohen and Fisher, it is understood that the isothermal transformation can eventually be suppressed but never the athermal.

Here exactly the opposite is observed; stabilization seems to have rendered athermal nucleation impossible and furthermore slowed up isothermal nucleation. More simply, in the temperature zone near T_{max} corresponding to a peak in the rate of nucleation, the latter is much too large to allow recording of the transformation, but by appropriate treatment the phenomenon can be slowed down enough to make it observable, by isothermal dilatometry for example. This nucleation can even be slowed down to the point of total suppression, everything being similar in other respects.

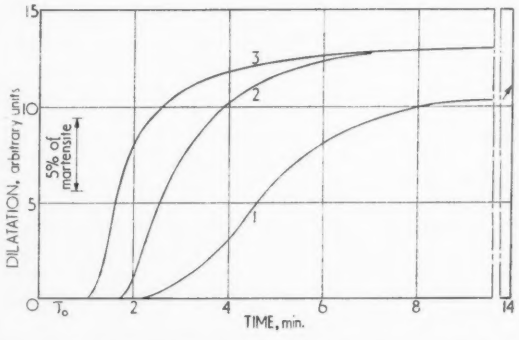


Fig. 11—Isothermal transformation at − 100° C. of specimens having undergone decreasing stabilizations in the order (1), (2), (3), duration and number of stabilization holding times being variable

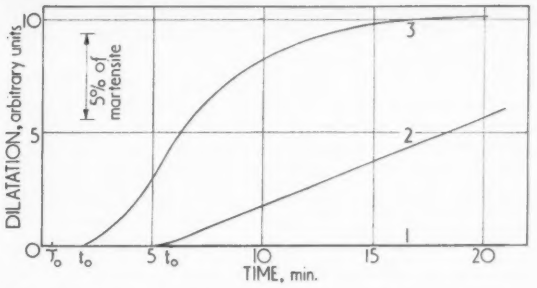


Fig. 12—Isothermal transformation of three specimens brought to − 60° C., raised to room temperature for ½ hr., then recooled to (1) − 80° C., (2) − 90° C., and (3) − 95° C.

There is no longer a question here of athermal martensite. It is much simpler to visualize a single mode of nucleation, and to ignore athermal formation. In this hypothesis, for plain carbon steels, the rate of nucleation is so rapid that the transformation appears to be ended as soon as thermal equilibrium is attained. In these conditions, by crossing, during cooling, a zone of temperature where this rate of nucleation is very large, it appears that the martensite forms on cooling, and that this formation stops as soon as the temperature becomes fixed.

In this connection, note that if cyclic cooling provides the most favourable conditions for observing isothermal transformations, it is not only because there is stabilization but also for the following reason. A specimen already transformed by a long holding time at T, is brought again from room temperature to $T - 20°$ C. It undergoes no transformation during cooling as far as T, but only during the passage from T to $T - 20°$ C., a much shorter period than the total time of cooling. If as well as that there is stabilization, the transformation does not begin again until a certain temperature M'_s. If cooling is carried out exactly to M'_s (or very near M'_s) no martensite whatever is formed in the course of cooling. It is therefore possible to study pure isothermal formation, without any anisothermal component.

The rate of transformation can even become so weak that the martensite does not appear till a long time after reaching bath temperature, i.e. so weak that the martensite does not appear in noticeable quantity (say ¼%) until quite some time after reaching bath temperature. This incubation time is clearly seen on the dilatometric recordings: the curve for the time to attain bath temperature is given by a line parallel to the time axis, before the dilatation due to transformation: this incubation time is variable as is seen in Figs. 10–12. These isothermals are shown starting at the moment when the dilatometric curve leaves the horizontal stage. After stabilization at room temperature the transformation restarts at a certain temperature M'_s with an incubation time of some tens of seconds, which time becomes nil some degrees lower. With very strong stabilizations, incubation times of even more than 5 min. may be observed (e.g. *see* Fig. 12). Note also that the length of the incubation period is associated with the rate of

subsequent transformation. The isothermals of Fig. 9 or Fig. 12 show that the slope becomes steeper when the transformation begins earlier.

This incubation time seems to correspond to a preparatory stage of transformation, e.g. to a stage of *slow growth* preceding the stage where each platelet grows at a rate near that of sound. Note also that certain isothermals (Fig. 11) present in their initial portions the shape typical of curves of transformation by nucleation and growth.

Thus interpretation of the results obtained requires the acceptance of the following two laws:

(i) There is only one mode of nucleation, athermal transformation being due to a 'perspective effect' depending on the time scale

(ii) Stabilization slows down the rate of nucleation to a very large extent, allowing observation of a reaction which is normally too rapid.

The second of these laws is known already in some alloys with an M_s point below 0° C., where the isothermal transformation has been studied, e.g. in ferro-nickels with 30% of nickel.[2] It can therefore be considered as quite general, and applicable to carbon steels in particular.

The first law is very strongly suggested by these results, if not indispensable for their explanation. Moreover, many recent published works have also suggested it. Note also that the effect of inverse stabilization which was observed in our experiments is manifested in certain cases, where the maximum rate of transformation is not too high, by the total suppression of transformation on rapid quench to very low temperature (below M_f).

One essential feature must be stressed: the individual formation of the platelets must be clearly distinguished from the overall formation of martensite (it is the latter quantity which is measured). The formation of each platelet is almost instantaneous, of the order of 10^{-7} sec. according to Mehl and Bunshah,[7] and corresponds to a particular mode of *growth*. The formation of plate *nuclei* is entirely different, and like some other nucleation phenomena, is largely controlled by the kinetics of thermal fluctuations. (The word 'isothermal' is really inadequate.)

These thermal fluctuations can, moreover, add their effect to the centres of pre-existing distortion, of the type considered by Cohen.

Unfortunately the rate of nucleation has not been determined as the size of the platelets is variable, as a result of the partitioning of the austenitic matrix. Using Boltzmann's law the rate of nucleation is:

$$\dot{n} = N\nu p.\exp\left(-\frac{W^* - W_0}{kT}\right) \quad \ldots\ldots(1)$$

where n = number of nuclei formed per unit volume and time
ν = frequency factor
p = number of modes of martensitic shear possible
N = number of centres of distortion per unit volume
W^* = free energy of activation, varying with temperature, of the critical size nucleus
W_0 = energy of centres of distortion.

The only theoretical calculation of the activation energy is that of Fisher[3] which supposes a nucleus growing from a centre of similarity until the formation of the final plate. He has shown recently that Cohen's conception of the nucleus,[1] where the angle of shear varies in time and space during growth, leads to the same formula for W^*, to a factor very near unity. These calculations are evidently unreliable, because of simplifications made for the calculation of deformation energy in the matrix or the variation of interfacial energy with the angle of shear. Nevertheless, this relationship has allowed Fisher to recalculate quite a large number of experimental results, for Fe–Ni–Mn[9] and the ferro-nickels,[4] e.g. the temperature T_{max} or the form of the isothermals, involving the adjusting of a certain number of constants.

This relationship of Fisher's which has permitted calculations in good agreement with experiment in the case of an Fe–Ni–Mn alloy with an M_s point about − 80° C. also allows satisfactory predictions for plain carbon steels.

According to Fisher:

$$W^* = \frac{8192\pi\sigma^3\lambda^2}{27\ \Delta G_v^4} \quad \ldots\ldots(2)$$

where σ = austenite/martensite interfacial free energy per unit area
ΔG_v = free-energy change between the two phases per unit volume.

$$\lambda = \tfrac{1}{6}\mu\gamma^2 \quad \ldots\ldots(3)$$

where μ = shear modulus
γ = martensitic shear.

Introducing all terms relating to centres of distortion into a single constant, N_0, the following is obtained:

$$\dot{n} = N_0 \exp\left(-\frac{8192\pi\sigma^3\lambda^2}{27\ \Delta G_v^4 kT}\right) \quad \ldots\ldots(4)$$

Taking 5×10^{22} as an average value for $\sigma^3\lambda^2$, after Fisher (who took $2{\cdot}9 \times 10^{23}$ for 3% Cr steels[3]; $5{\cdot}85 \times 10^{22}$ for an Fe–Ni–Mn alloy[9]; $9{\cdot}92 \times 10^{21}$ for some ferro-nickels[4]), a value which corresponds to $\sigma \sim 6$ ergs/sq. cm., and taking γ as 0·35 (for low-carbon contents), the following is obtained:

$$\frac{\dot{n}}{N_0} = 10^{-21} \quad \ldots\ldots(5)$$

using $\Delta G_v T^{-\frac{1}{2}} = 1525$, at M_s, for a 0·8% C steel.

Let us now consider what values can be allowed for $\dot{n}$ in the region of M_s. Greninger[10] studied the invariance of M_s for extremely variable rates of cooling. Thus, for a specimen with 0·84% of carbon, quenched into a metal bath held at 221° C., the rate of cooling near M_s was almost nil; a specimen cooled in gas at a rate of cooling of 4000° C./sec. at 550° C. cooled at a rate of about 1400° C./sec. near M_s. However, these two experiments gave values of M_s agreeing within the limits of error (say about 2° C.), which correspond to less than 0·5% of martensite in $1{\cdot}4 \times 10^{-3}$ sec. Taking a value of 10^{-12} c.c. as the minimum volume of martensite needles, the rate of nucleation must be greater than $\frac{1}{2} \times 10^{-2}/10^{-12} = \frac{1}{2} \times 10^{10}$ nuclei/c.c. formed in $1{\cdot}4 \times 10^{-3}$ sec., say 10^{12} nuclei/c.c./sec.

In fact, Greninger has been able to reach quench rates of 12,000° C./sec. at 550° C. with a bath at 20° C. Assuming, in these conditions, a rate of cooling as large as 10,000° C./sec. near M_s, and an accuracy

of measurement equal to that in the preceding experiments,* it can be concluded that the rate of nucleation must be greater than 10^{13} or 10^{14} nuclei/c.c./sec. Hence

$$N_0 > 10^{35} \quad \ldots\ldots(6)$$

Now in a theoretical study of the isothermal transformation of the alloy investigated by Cech and Hollomon,[11] Fisher has been led[9] to take $N_0 = 10^{36}$. Thus, such a value of N_0 is equally suitable in explaining the slow nucleation in this alloy as of the ultra-rapid nucleation in carbon steels. This shows the mode of nucleation in such very different alloys may well be identical.

It is, however, necessary to answer the question of why the transformation does not go to completion at any given temperature. The formation of platelets sets up considerable stresses in the surrounding material, mainly around platelets which appear simultaneously by a co-operative mechanism of formation: the constraints set up in the matrix are then considerable (compression stresses can reach 250 kg./sq. mm.). The matrix surrounding these platelets is then stabilized: a larger free-enthalpy term ΔG is now required, i.e. a lower temperature to provide the energy necessary to overcome these constraints in order to form new plates.

In the transformation during cooling, if at each temperature only a few per cent. of martensite is formed, a mean value $A(T)$ for the volume of platelets at each temperature can be assumed. More precisely, each nucleus of equation (4) can cause the appearance of one or several platelets (by co-operative mechanisms). $A(T)$ designates then the mean volume of martensite formed per nucleus.† This applies to the region around M_s; as soon as a certain quantity of martensite has formed, such co-operative phenomena are no longer possible as a result of the partitioning of the austenite by the martensite platelets. As the temperature is reduced, the increasing degree of partitioning reduces the average dimensions of the platelets and also the average volume of martensite formed per nucleus; $A(T)$ is therefore some direct function of T.

Thus the stresses and deformations resulting from the formation of martensite and which have been aiding its further nucleation are progressively exhausted. There remain the stresses and deformations which hinder nucleation; these are the more numerous since the others were only found in preferred directions. The mechanical effort required to work against these stresses necessitates, all things equal in other respects, a larger ΔG, i.e. a lower temperature. When the austenite is well 'partitioned' it may be submitted to very high compressions, up to 200 kg./sq. mm. according to Houdremont and Krisement,[12] which considerably hinder all nucleation.

It can thus be considered that at a given temperature T there is a residual volume of austenite V where nucleation is possible. A certain number of plates $N(t)$ of average volume $A(T)$ appear, where t is the time at temperature T. These prevent all nucleation at temperature T in a certain volume surrounding the platelets already formed. This volume will be called $p.A(T)$. It follows from previous considerations that p is constant or decreases with lowering temperature. If in the time t, $N(t)$ plates have appeared, there will be formed in the time dt, and in the volume $[V - N(t)p.A]$ where nucleation is still possible at temperature T, the following number:

$$dN = \dot{n}[V - pAN(t)]dt \quad \ldots\ldots(7)$$

if it is assumed as a first approximation that the rate of nucleation $\dot{n}(T)$ is only a function of temperature and remains constant in time at a given temperature of transformation:

$$N = \frac{V}{pA}[1 - \exp(-pA\dot{n}t)] \quad \ldots\ldots(8)$$

The value of N tends to a limit equal to V/pA and thus the quantity of martensite which can be formed at temperature T cannot exceed V/p, where V and probably p are functions of temperature. The transformation is therefore limited at all temperatures. If the rate of nucleation is particularly rapid, this limit is reached very quickly and the transformation is observed solely as a function of the lowering of temperature. In the middle of the range of temperature in which transformation is observed the ratio V/p varies little; an almost linear transformation curve (% martensite/temperature) is thus obtained. There is no departure from this straight line till near M_s, where V is relatively large and where the quantity of martensite increases quickly with lowering temperature, and in the region of M_f, where V becomes very small as a result of the very high values of the compression stresses; the quantity of martensite formed at each temperature gets smaller and smaller.

Thus the hypothesis of nucleation by thermal fluctuations takes account not only of all the characteristics of martensitic transformation in ordinary steels, but also is the only one which allows interpretation of the majority of the results recorded in this paper. Furthermore, it leads to the presentation of a unified picture of martensitic transformations in steels and ferro-alloys. Note that the accepted ideas are that martensite is formed athermally in steels whose M_s point is quite high (say about 100° C.), athermally and isothermally in alloys with a low M_s point (generally less than 0° C.), and purely isothermally when the M_s point is still lower (about − 80° C.). In our view this division is due to variations in nucleation rate, on the average progressively greater with higher transformation temperatures, i.e. in actual fact to isothermal reactions less and less observable reaching an apparent 'athermality' at the highest transformation temperatures.

SUMMARY AND CONCLUSIONS

The martensitic transformation has been studied in a hyper-eutectoid chromium steel with 1·4% of carbon and 2·5% of chromium, whose M_s point is slightly above room temperature. The following results have been obtained.

* Greninger gives no numerical result for rates of 12,000° C./sec.

† The nuclei concerned are those formed from the pre-existing embryos of deformation. In co-operative effects, each platelet causes new embryos to appear, and so new nuclei and new platelets: all these latter are here attributed to the first nucleus of the chain of platelets.

(1) The thermo-electric power varies linearly with the percentage of martensite.

(2) The rate of transformation accelerates very rapidly below M_s, passes a very sharp maximum near — 20° C. and then follows a curve falling hyperbolically to become nil at — 150° C. (the M_f point).

(3) On direct quench, with different rates of cooling, an inverse stabilization effect is noted as well as normal stabilization.

(4) Direct stabilization by returning to and holding at temperatures equal to or above room temperature slows down the rate of transformation and allows complete recording of the isothermal reactions without interference from parasitic anisothermal reactions.

(5) After stabilization the transformation resumes at a temperature M'_s at a very slow rate and with an incubation time which can exceed 5 min. At temperatures below M'_s the transformation begins more and more rapidly with shorter and shorter incubation times.

(6) Austenitizing and quenching conditions being equal, raising the stabilizing temperature or increasing the length of the stabilizing treatment gives a stronger stabilization and lowers M'_s.

(7) At a given temperature, a stronger stabilization is manifested by a slower rate of transformation and an increased incubation time.

(8) Nucleation is not athermal, but due to thermal fluctuations, so that all the martensite can be considered as forming in isothermal increments. This conclusion is general for all martensitic transformations and carbon steels form a particular example.

(9) Fisher's theoretical formula for the energy of activation of nuclei allows a determination of the nucleation rates by thermal fluctuations, based on Boltzmann's law. The calculated rates of nucleation are large enough to justify the invariance of M_s with the highest rates of cooling reached in Greninger's experiments.

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DISCUSSION

Professor **C. Crussard** presented the paper.

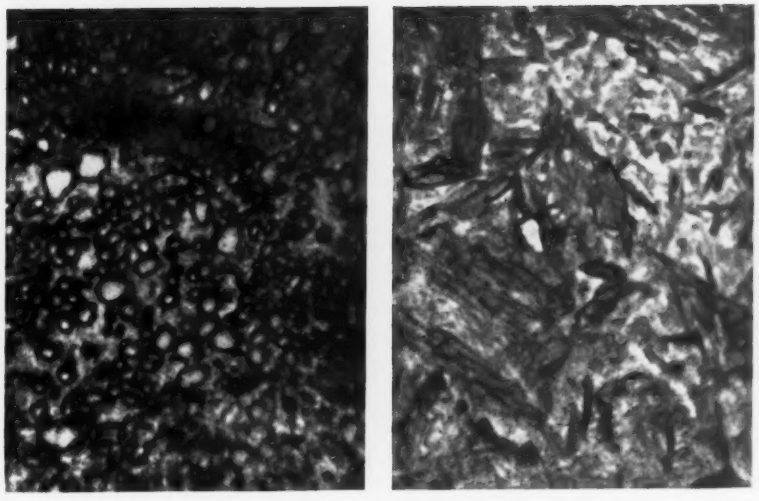
Dr. **A. P. Miodownik** (Battersea College of Technology): It is interesting to solve the problem of isothermal martensite by saying that it is the athermal martensite which is really the peculiar phenomenon, and that martensite is basically an isothermal reaction. This is however not sufficient, because if one describes the reaction as proceeding by nucleation and growth one must still make some distinction between a reaction which proceeds by nucleation and growth as rapidly as the martensite reaction does and a reaction which proceeds by nucleation and growth in the way of a conventional diffusion reaction.

This brings me to a problem of which so far I have been given no explanation. Is martensite formation the result of growth of a needle gradually increasing and spreading across the grain, or does it grow in the form of a discontinuity like a twinning dislocation right across and then gradually increasing about the mid-rib ? If it proceeds in the first way, it looks very much more like an isothermal reaction, but if it proceeds in the second way we cannot call it isothermal in the sense in which the word is normally used.

Kurdjumow has established for several non-ferrous alloys—copper–aluminium, copper–aluminium–nickel, copper–tin, and iron–nickel—that there are two different types of martensite, one which he calls elastic and one which is anelastic. The elastic one grows very slowly with decrease in temperature, and then if the temperature is reversed it gradually ' de-grows ' and disappears again. If there are several of these martensite plates and their order of formation is noted, it will be found that they disappear in the reverse order in accord with the distribution of stress. Do the authors think that their isothermal growth behaviour accounts equally well for these two types of martensite, or only for the type of martensite which occurs in ordinary steels ?

I should like to know the authors' ideas on the stabilization phenomenon. As far as I can see, if one has a maximum rate of transformation at some stage and the specimen does not transform there because of stabilization, the whole problem devolves on the precise nature of stabilization. Could this have anything to do with the relaxation of stresses which have occurred during cooling ?

On this point I can only offer some experimental results of my own, which unfortunately are on copper–tin and not on steel; nevertheless I think that they are relevant. If the rate of cooling is reduced, a diminution in the amount of martensite at room temperature is noticed until eventually only the parent phase is retained. In some of the alloys this is accompanied by the presence of polygonization boundaries. At first, sub-boundaries form a background to martensite needles; but gradually the sub-boundaries strengthen in such a way that they obstruct martensite formation. When considering a



(i) (ii)

Fig. A—Photomicrograph of 0·65% carbon steel : (i) spheroidized ; (ii) carbide nucleus left in the martensite. Nital etch × 2400

grain, faint sub-boundaries are first observed with the martensite going right through; at a lower rate of cooling the sub-boundaries are slightly more prominent, and the martensite is now confined to the individual sub-cells; at still lower rates of cooling the martensite disappears altogether, and instead growth of some isothermal character on the sub-boundaries is observed. In the last case the original grain is being used up by some other process and therefore martensite cannot be obtained, but the effect where the martensite is obstructed by the sub-boundaries seems to be of importance if polygonization is interpreted in terms of relief of stress.

Not having seen the original paper, I do not know how much emphasis is put on any internal stresses, as distinct from nuclei and embryos and all the usual activation energy concepts; but I consider that the internal stresses play a very pronounced part. The phenomenon quoted is not confined to copper–tin alloys, but is also very prominent in titanium alloys, and the stabilization in those is extremely rapid; I believe that stopping for 2 or 3 sec. at 600° C. will completely inhibit martensite formation on quenching from 1000° C., whereas with an uninterrupted quench prolific martensite is obtained.

Professor **Crussard:** Those remarks are extremely pertinent to the question of martensite distribution, the question of how martensite grows, and what we mean by isothermal transformation. We mean by isothermal transformation that the nucleation process occurs as perhaps in some other transformations, but that does not mean that the growth occurs as in other conventional nucleation and growth processes. We tackle the problem of the growth of martensite in the light of the new experiments of Bunshah and Mehl, who proved that the rate of propagation of the growth process is about the velocity of sound. Their results show a first step in the transformation which may be called supersonic, because it goes rather faster than sound. At the same time there was published in Germany a paper by Wever, Houdremont, and Krisement dealing with the conception of martensite as an adiabatic transformation, taking into account the fact that if in a small volume the transformation heat is produced, and it has not time to escape, the whole volume must be at a much higher temperature than the M_s point; this heating effect is taken into account by their theory, but they do not consider the fact that there is some kinetic energy developed if there is some wave propagation.

We are now considering a theory on lines familiar to those who deal with explosives, the lines of shock and reaction. If a theory is developed on those lines, the first of the two processes of propagation to which reference has been made is the true one; it must propagate as a front, and there is first a cooling of the metal and after that the transformation which heats the metal again, and then there is a return to the final state. We have not finished all the calculations, but the order of magnitude seems to be quite correct. We visualize a shock wave which is going faster than sound. This picture seems to be correct, because this shock wave gives a very thin layer with high distortion, and after that there is a period of plastic accommodation with this high elastic distortion which takes a longer time. We can say, therefore, that with certain types of what we call true martensite this type of shock wave does exist. It does not mean that another type of diffusionless transformation cannot occur. This is what Kurdjumow called the anelastic martensite, which has been found with a great number of metals, and the variety of crystallographic mechanisms of this type of transformation is infinite, so that we have not dealt with it.

With regard to the question about stabilization, I quite agree that there is some difficulty, and that the time-dependent process could be stabilized in the way suggested. That is why we are making experiments now in the M_s region, but they are much more difficult, because the reaction is very rapid. We have not yet been able to detect the rate there, and we cannot give the experimental results. The result shown by Dr. Miodownik is extremely interesting and agrees rather well with what we have found about stabilization in our first study, viz. that this stabilization must be due to some variation in structure which is certainly related to the dislocations. Either the stabilization is related to the formation of clouds around dislocations of polygonization walls, or it is due to a true precipitate of sub-microscopic carbides, or is it due to the aggregation of vacant lattice sites. In any case it is related to some hardening process or some process which changes the energy of the austenite round the martensite plates.

Mr. **A. W. J. van den Bergh** (Kromhout Motoren Fabriek): In connection with the question of martensite formation, I should like to refer to a moving film made by Professor Hanemann in Germany before the war, of which there is only one copy extant. There the growth of the martensite can be seen taking place in the way that Professor Crussard has suggested, like an explosion (the German word is 'stossweise'). The growth starts somewhere on the boundary, perhaps where there is a high concentration of austenite, and then it can be seen growing throughout the grain.

I made a study of it in steel-hardening practice in several types of steel, among which was a 1 : 1 : 1 : 1 carbon–manganese–chromium–tungsten steel. As this steel can be austenitized (with induction or flame heating and even in furnace heating with sufficient capacity) 'incompletely,' a certain percentage of austenite transformed (say 80%) will leave many small carbide remnants going from a micro-structure of carbides in the globularized form; in this phase it may be water-quenched very quickly, in the course of which there will be a very short austenitizing time with the following results.

The carbides can be dissolved until only a very small carbide nucleus is left. In the matrix there may be a difference in the completeness of solution of the carbide.

Starting with the solution the matrix is almost completely ferritic, with very well distributed carbides in it in the form of balls of a certain dimension (*see* Fig. *A* (i)); the carbon atoms now have to go through the ferrite for which they need considerable time: this is the diffusion phase. The outside of the carbide balls is 'attacked' and so solution takes place until no carbide ball is left; this takes place in the soaking time. But when the time is made relatively short, those 'carbide balls' which are left may be trapped and protected against full solution. The result is an even distribution of small carbide nuclei left in a matrix of austenite. If it is quenched in this state, the result is that the martensitic explosion-like transformation takes place starting from these remaining carbide nuclei and therefore evenly distributed martensite transformation will take place throughout the piece, forming a 'low-tetragonal' martensite, the product found also in the martempering technique with salt-bath treatment.

The difference from the normal 'high-tetragonal' martensite is that the steel undergoes a volumetric change of 4% increase and in tempering a 2% shrinkage at tempering temperature, i.e. altogether a 6% volume change.

With direct transformation to low-tetragonal martensite, there is only a 2% shrinkage volume change, which avoids cracking.

It might be considered a very difficult problem for a heat-treater to harden the type of steel mentioned in water, but we succeeded in doing it without any cracks and with very intricate shapes, involving sharp corners which we made specially in the test pieces.

After quenching this 'unsaturated' austenite, we actually found in the micro-structure (examined immediately after water-quenching without 'stress-anneal' or temper) small 'trapped' carbide nuclei, which had been left after incomplete austenitizing and had acted as evenly distributed starting points of a very fine needled low-tetragonal martensite.

The more small carbide nuclei there are which are left after austenitizing, the more starting points for even martensitic explosion-like transformation (with, moreover, less retardation in transformation and no danger of 'retained austenite'), the better the results in hardness distribution, and the better the stress distribution throughout the piece and the less danger of cracking.

Remarkably, 62 Rockwell *C* is a fairly normal hardness in most steels; steels with complex carbides have a figure only slightly higher.

I have published this information elsewhere.* Mr. Howard E. Boyer, Chief Metallurgist of the American Bosch Corporation, who was on the editorial board of the journal concerned, commented that since 1943 the American Bosch Corporation had used this technique for the heat-treatment of injection equipment for Diesel engines. They had never mentioned or published this during the war, but when I published my study and theory, he agreed that it was the same and said: "This must belong to one of the fundamental principles of metallurgy."

On the other hand there will be a considerable growth in big austenite grains when the piece is austenitized fully and the martensite transformation and 'big-grain explosions' are retarded through undercooling the austenite during quenching (when no carbide nuclei are available for starting transformation). When transformation takes place suddenly at a rather low temperature the result is hidden so that it is nearly impossible for the steel to follow the much bigger explosion-like volume changes at the strength and hardness already reached; this results in unevenly distributed stresses and finally in cracking.

We use this technique in special steels for Diesel injection equipment, tool steels, etc., and also in flame-hardening the most varied types of steels ranging from high-alloy tool steels to normal 0·6% carbon steels.

As the matrix results in rather 'tough' martensite with evenly distributed carbide nuclei, wear-resistance is excellent.

The carbides, whether complex or not, will act as the 'wear-bearing' elements. In fact, in hypo-eutectic tool steels the wear-resisting properties come from the same origin. This is illustrated in the microphotograph, Fig. *A* (ii), where a carbide particle is seen left in a matrix of fine martensite, where $H_{c30}=750$.

Dr. **K. Sachs** (G.K.N. Group Research Laboratory, Wolverhampton): Referring to the remarks of a previous speaker I can see some advantage in practice in a short austenitizing period, because a small amount of carbide left behind will stop grain growth; but I do not think we should accept the suggestion that residual carbide particles will act as nuclei for martensite formation. I believe that any small amounts of carbide found in martensite needles are simply bits of carbide which were not dissolved, and the martensite has formed round them.

With regard to the main paper, there is a point which puzzles me about the isothermal formation of martensite, with the implication, of course, that it is still completely diffusionless; isothermal martensite transformation differs from ordinary isothermal transformations in stopping short very suddenly after a certain amount of martensite has been formed. There is a need to account for this phenomenon, presumably in terms of stress; but as soon as stress is introduced it must be recognized that further cooling will affect the stress distribution.

The rate of transformation and the rate of nucleation are normally regarded as being a balance between the free energy gained as a result of fall in temperature and the decrease in the rate of diffusion as the temperature falls. If there is diffusionless transformation it implies that the rate of transformation and the rate of nucleation should increase continuously as the temperature goes down, with the maximum rate of transformation and the highest number of nuclei at the lowest temperatures, because the free energy liberated by cooling will be greatest at the lowest temperatures.

Professor **Crussard**: I agree with Dr. Sachs that it is, perhaps, not a question of nucleation, but of the carbides being an obstacle to growth. If there is not complete dissolution, there must be around the carbides a small spherical zone of higher carbon concentration, because when a carbide is dissolving the composition gradient is moving. It is thus most difficult to transform this type of steel to martensite, and this type of steel is useful as cutting steel, because the carbides are embedded in a matrix of austenite which is tough; that is why I think martensite does not start from there but arrives there.

On the question of the difficulty about diffusionless growth, I do not think that there is really a difficulty, because the rate of nucleation is proportional to some exponential function of W/KT, or, if not T, then a function rather similar to T (*see* p. 46). The value W is decreasing as the temperature decreases, but after some time the effect of T also decreases. That is why any type of nucleation passes through a maximum. I do not think that there is any theoretical difficulty about that. The value W is the difference between the free energy state of γ and α, and thus it is decreasing as the temperature decreases, but the other term is also decreasing.

Dr. **Sachs**: The point about T is that it becomes increasingly difficult for atoms which are going to form the nucleus to get together.

Professor **Crussard**: For any activation process even without diffusion there is the same type of formula.

Mr. **C. Edeleanu** (The Brown-Firth Research Laboratories): I am curious to know what happens in the surface layers. The martensitic transformation is presumably much more restricted in a three-dimensional body than in the more or less two-dimensional region near the surface. Do the authors think that the effect, if any, would be sufficient to raise the M_s on the surface by an appreciable extent? If this effect is likely to be appreciable, an additional complication to microscopic determinations of M_s should be the nature of oxide films present. Presumably in borderline cases it should be possible to induce the martensitic transformation by 'etching' the oxide away. Has this or any related phenomenon been noticed by the authors?

Professor **Crussard**: That is difficult to answer. The surface does play a different role, and, whilst it is true that the average M_s is not the same as that of the middle of the specimen, it is difficult to say whether that is a true surface effect or due to the gradient of quenching stresses.

*A. W. J. van den Bergh: *Steel Processing*, 1952, vol. 38, p. 139.

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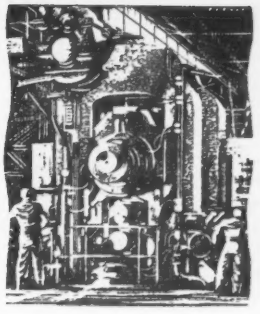


Cold Working of Metals

By J. G. Wistreich, M.Sc.(Eng.), D.I.C., A.M.I.Mech.E.

SYNOPSIS

Attention is drawn to concepts of general significance in the mechanical working of metals, with the help of which understanding of the processes and their improvement may be furthered. Particular importance is attached to the concept of tool-stock configuration and its role in determining the properties of end products, tool loads, and machine size. Reference is also made to the yield-stress curve, to patterns of deformation, and to volumetric stresses. Illustrations are taken from rolling, drawing of wire, bar, and tube, and from cold extrusion. 1055

THE SCIENTIST in the metal-working industry is still something of a new boy, who often merely discovers why some things are best done the way they are being done, whilst his industrial colleagues contrive to keep one jump ahead of him by a nice blend of experience, skill, and inventive genius. Nevertheless, even at this comparatively early stage of his apprenticeship, the scientist can render useful service to this ancient industry by underpinning accumulated knowledge with fundamental notions. By doing this he not only builds a firm foundation for future progress, but he also makes it easier for what is already known to be put to more effective use. This is of particular value in this industry, which has its roots in the most distant past and the branches of which have grown independently of each other, with little or no intercommunication, leaving much scope for the transference of 'know-how' from one process to another.

The prerequisite of communication is a common language, and the fewer and simpler the signs of this language, the more efficient the communication. With this thought in mind, it is proposed to review briefly the field of the cold working of metals, emphasizing some of the more important objects of the scientist's study.

For this purpose three facts must be borne in mind. The first is that the main purpose of metal working is to change the shape of a lump of metal. Consequently, geometry plays a dominant part in the science of metal working, although the practical geometry of metal working is often at variance with Euclid's theorem about the shortest distance between two points. The second fact is that metals put up strong resistance to deformation, particularly at room temperature. The magnitude of the forces needed to overcome this resistance and the manner of their application govern the design of tools and machines and influence the choice of the path from initial to final shape. The third fact is that deformation changes the properties of the metal—for the better in some respects, for the worse in others. This means that, in addition to geometrical and kinematic considerations, it is necessary to take account of the interplay of the change of shape and of the change of properties.

PLASTIC BEHAVIOUR OF METALS

In dealing with this subject, one is faced with a paradox from the outset. The behaviour of metals is dominated by their crystalline character. The regular and highly symmetrical arrangement of atoms is responsible for the distinctive patterns of flow observed in wrought metals, it accounts for their selective reaction to external forces, and it is at the root of differences between individual metals. Yet the relative ease with which the shape of metal objects can be changed, the magnitude of the change that is

This paper was presented to a joint meeting of The Liverpool Metallurgical Society and the Iron and Steel Institute, held at The Temple, Dale Street, Liverpool, on 8th April, 1954.

Mr. Wistreich is Head of the Metal Working Laboratories of the British Iron and Steel Research Association in Sheffield.

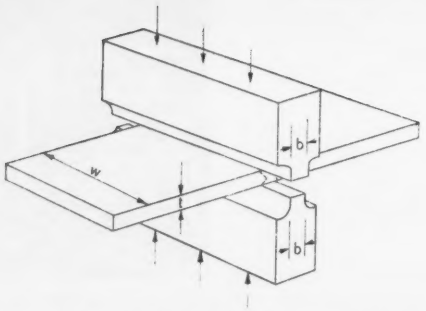


Fig. 1—Plane-strain indentation by flat tools[15]

possible without fracture, and even their characteristic tendency to work-harden, are all caused by irregularities in the atomic arrangement. Some of these crystal imperfections have been understood for a long time and have been put to practical use by metallurgists, particularly in the manufacture of alloys stronger than the solvent metals e.g. the distortion of the crystal lattice by foreign atoms). The other kind of imperfection, the one which facilitates deformation by virtue of its dynamic character, had until recently existed only in the minds of mathematicians. But within the last few years the 'dislocation,' as this imperfection is called, has become a physical reality.

In the present state of research much remains to be learnt about dislocations before they can be brought

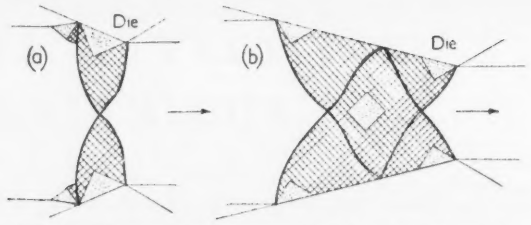
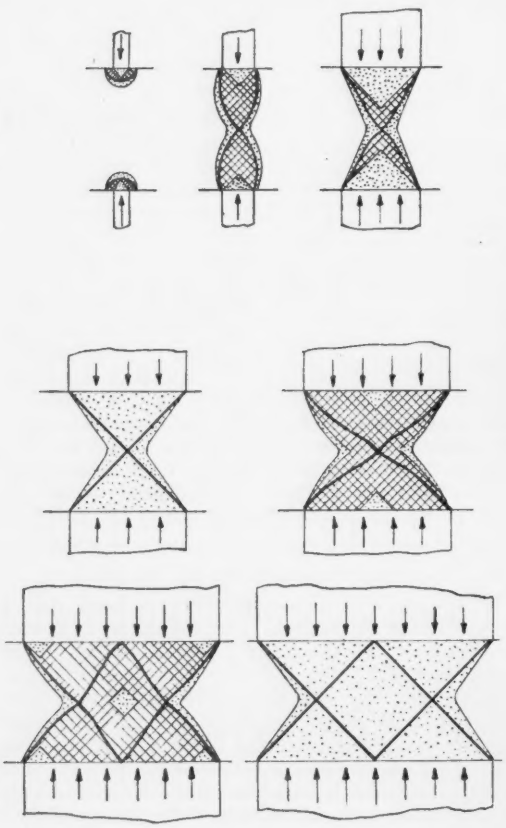
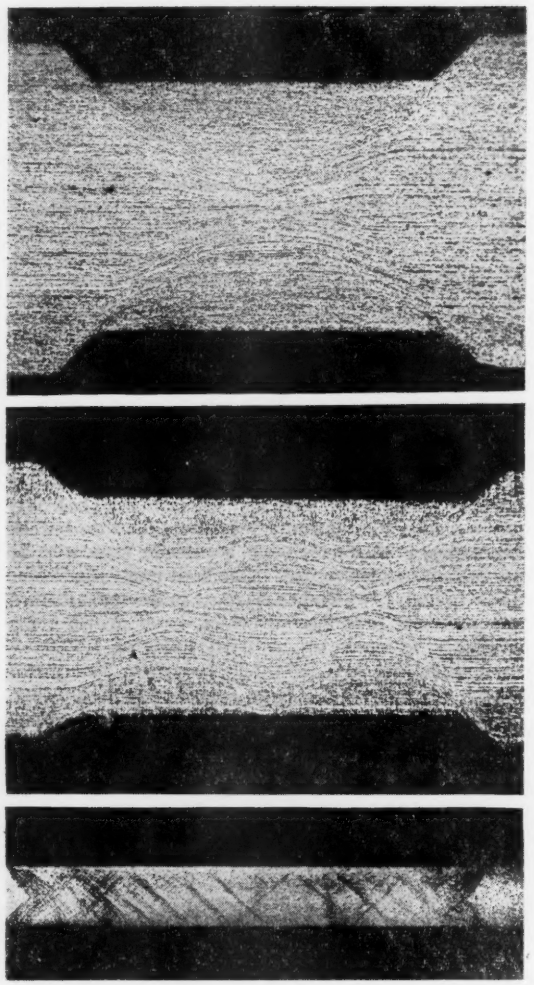


Fig. 3—Deformation patterns in sheet drawing[2, 3]

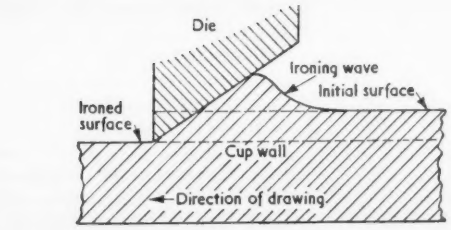


(a)

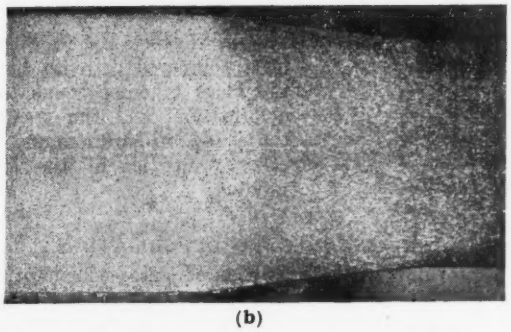


(b)

Fig. 2—Deformation patterns in plane-strain indentation[2]: (*a*) Theoretical; (*b*) experimental (top and middle in Al–Mg alloy, bottom in mild steel)



(a)



(b)

Fig. 4—(*a*) Bulge in bar drawing and in ironing of cups; (*b*) boundary of plastic deformation in wire-drawing

under full control. But what is already known about them is of great interest and potential value to those concerned with wrought metal products. The yield strength of an ordinary crystal of tin is about 200 lb./sq. in.; that of a very thin tin whisker, which so far is the only known form of a crystal deficient in dislocations, is about 200,000 lb./sq. in. The maximum elastic strain of a tin whisker is 3%; that of piano wire, which is the strongest form of wrought metal known, is only about 0·5%.[1] Perhaps it may one day be possible to control the presence and behaviour of dislocations so that during shaping a metal is no stronger than the ordinary single crystal of tin, but that the final product may be endowed with the strength and elasticity of the tin whisker.

DEFORMATION PATTERNS IN METAL WORKING

In the meantime, however, the behaviour of dislocations has to be accepted as beyond control. What is important practically, however, is that these movements are not entirely random and that a metal crystal deforms locally, and more readily in some directions than in others. A preference for local and oriented deformation is characteristic not only of single crystals but also of polycrystalline assemblies worked in industry. Thus, although from the point of view of pure geometry there is an infinity of modes of transforming one shape into another, the deformation of metals follows distinctive patterns which, for practical purposes, may be summed up in terms of a simple serviceable rule, as follows:

> The change of external shape in cold working is attained by local rather than by uniform deformation of the interior of the workpiece, and the pattern of deformation is determined mainly by the configuration of both tool and work-piece.

These patterns can be revealed by a variety of metallographic methods. Figure 1 illustrates the process of flat tool indentation, which has been thoroughly examined theoretically, as well as experimentally. Now, as the breadth of the tool is changed in relation to the thickness of the work-piece, so the mode of deformation changes. The patterns of deformation calculated by the mathematicians[2] are illustrated in Fig. 2*a*; the heavy lines denote narrow regions of intense deformation by shearing, in the cross-hatched areas the deformation is diffuse, and in the areas shown dotted no deformation occurs, even though the metal is stressed right up to the verge of what is needed to deform it. Patterns actually occurring in metals are shown in Fig. 2*b*; these patterns are not as sharply delineated as the theoretical ones, but they nevertheless reveal the same characteristic dependence on tool-stock proportions.[2]

This connection between tool-stock configuration and pattern of deformation is also found in industrial processes. Figure 3 shows theoretical patterns for strip drawing[3]: Fig. 3*a* represents the extreme case of a very short tool-stock interface, with the stock bulging ahead of the die, and Fig. 3*b* is for a long interface and is rather more diffuse. Note, incidentally, the resemblance between drawing and indentation patterns (Figs. 2*a* and 3). The contour plots in Fig. 4*a* confirm the occurrence of bulging in bars and in thick-walled cups.[4] A similar bulging is also found in wire drawing.[5] Figure 4*b* is of a partly drawn wire sectioned and etched to reveal the boundary of the deformation zone at entry to the die[6] and should be compared with Fig. 3*b*.

MECHANICAL PROPERTIES OF END PRODUCT

Since some portions of the metal are deformed very heavily, whilst others remain almost in their original state, it is not surprising that the properties of the end product also vary from point to point, and the

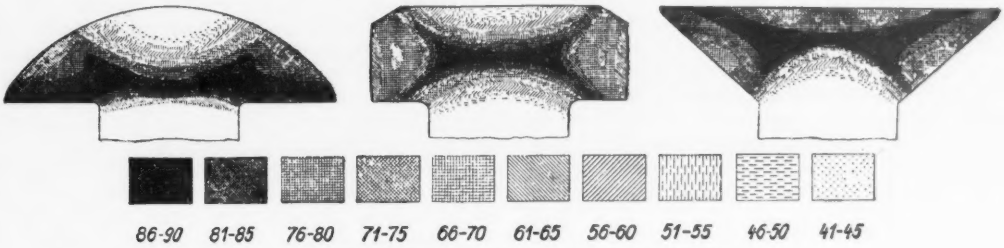


Fig. 5—Strain patterns in cold heading[7]

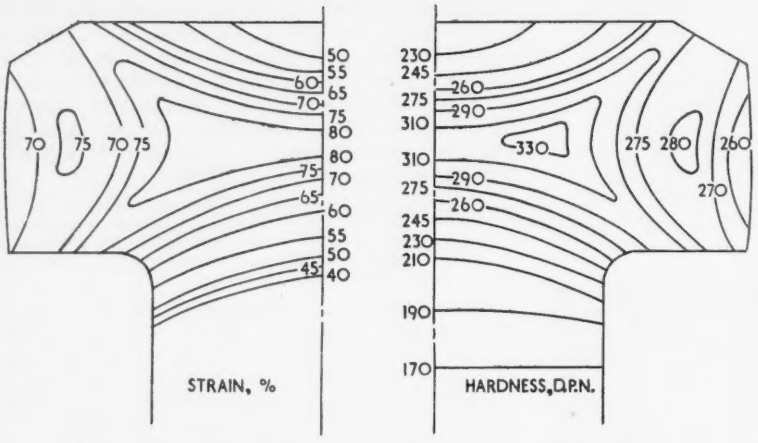


Fig. 6—Distribution of strain and hardness in cold heading[7]

variation may be quite considerable. The correspondence of patterns of deformation and of properties is brought out by Figs. 5 and 6, which show, respectively, the strain and hardness distributions in bolt heads.[7]

In continuous processes, such as rolling and wire drawing, the effect of the deformation pattern on the properties manifests itself in a rather different way, since each particle of the metal has to traverse the zone of deformation. Figure 7*a* and *b* are evidence that the properties of drawn wire depend not only on external change of shape, but also on tool-stock configuration; in the former the reduction was kept constant and the die angle varied,[8] in the latter the die angle was kept constant and the pass reduction was varied.[9] Similar effects are also observed in rolled strip. Often the change in the average properties of the work-piece is appreciably greater than can be deduced from the external change of shape.

The tool-stock configuration also influences the residual stresses in the end product; these are beneficial in some instances, harmful in others. In rope wire, for example, the lowering of the limit of proportionality, which is one of the manifestations of residual stresses, is welcome, but in wire for prestressed concrete it is to be avoided. In cold-drawn bars high residual stresses in the skin are detrimental to subsequent machining, and also influence the fatigue strength of the stock.[10] They may be kept within bounds by a suitable choice of tool-stock configuration in the final pass (Fig. 8).[10] In some non-ferrous and high-alloy steel tubes high residual stresses cause cracking, either season cracking or cracking during subsequent heat-treatment.[11] Here, too, a suitable tool-stock configuration will eliminate the fault. In mild-steel sheet for autobody pressings residual stresses are helpful because they suppress the fault known as 'stretcher strains.' A light pass in the temper mill is most effective for this purpose because the tool-stock configuration is such as to promote inhomogeneity of deformation; i.e. the arc of contact in a conventional temper mill is shorter than in normal rolling owing to the light reduction in the pass. The arc can be shortened further by reducing the roll diameter, with the result that the immunity against stretcher strains is maintained for a longer period of time.[12]

In general, it may be said that the tool-stock configuration strongly influences the properties of the end product by virtue of its effects on the pattern of deformation. The smaller the area of contact between the tools and the work-piece compared with its bulk the more inhomogeneous the deformation, and the greater the change in hardness and in other properties of the end product.

RESISTANCE TO DEFORMATION

In dealing with the problem of energy consumption and of tool loads, the most conspicuous factor is the so-called 'stress/strain' curve. Figure 9 explains diagrammatically how it is related to the familiar load/extension diagram of the tensile test, and indicates some of its useful properties.

The stress/strain curve is, in effect, the 'identity card' of the metal in plasticity. Its shape tells the specialist a good deal about the workability of the metal, particularly in processes in which the forces are predominantly tensile (e.g. in deep drawing and in stretch-forming). It is also an essential ingredient of load and energy calculation; in particular, if the loads and energy consumption are known for one metal, this knowledge may be applied to other metals with the help of their stress/strain curves. It also gives a general indication of what mechanical properties are likely to be found in the end product.

The stress/strain curve may also be considered as representing the ideal metal-working process; it is impossible to find a process consuming less energy than is indicated by the stress/strain curve. An analogy with heat engines is useful in this context: just as no real heat engine can turn out the specified power from less heat than indicated by its appropriate Carnot cycle, so no metal-working process can produce a specified change of shape by less work than what is prescribed by the appropriate area under the stress/strain curve. For this reason the stress/strain curve is a convenient yardstick of energy consumption and, in practice, different metal-working processes may be compared with regard to their efficiency by reference to the stress/strain curve, just as different heat engines are compared by reference to the Carnot engine. Reckoned in these terms, strip rolling, with efficiencies ranging from 75% to 95%, ranks better than wire drawing, with efficiencies ranging from 50% to 75%, and wire drawing better than extrusion, with efficiencies from 30% to 60%. With efficiency data available from past experience, and with the aid of the stress/strain curve, it is possible to estimate the power required for a new plant.

There are two reasons why industrial processes consume more energy than the ideal process represented by the stress/strain curve. One is the presence of friction between tool and work-piece during sliding. The work of friction may be quite substantial, even though with good lubrication the coefficient of friction in many industrial processes is nearer 0·01 than 0·10, as was once supposed.

The other reason is that the tool loads are usually higher than the stress/strain curve suggests, owing to the fact that the metal is prevented from deforming freely. Figure 10 shows diagrammatically how one type of this constraint on the free deformation of metal is brought about. In the heading process

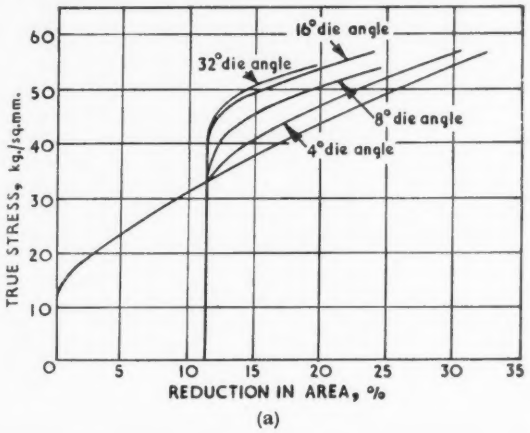


Fig. 7—Stress/strain curve of drawn wire showing effect of (*a*) die angle,[8] (*b*) reduction per pass[9]

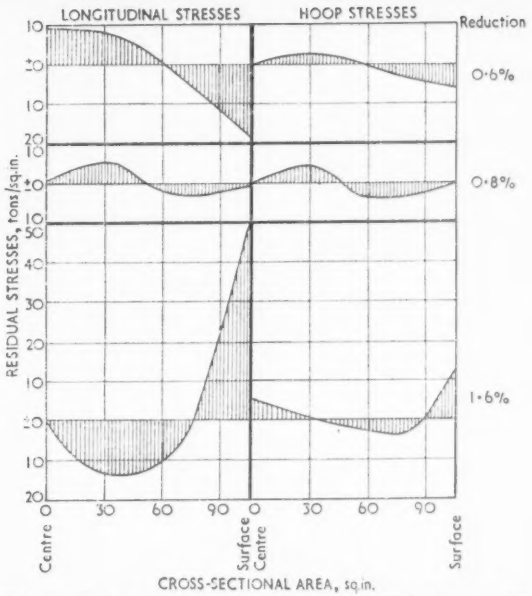
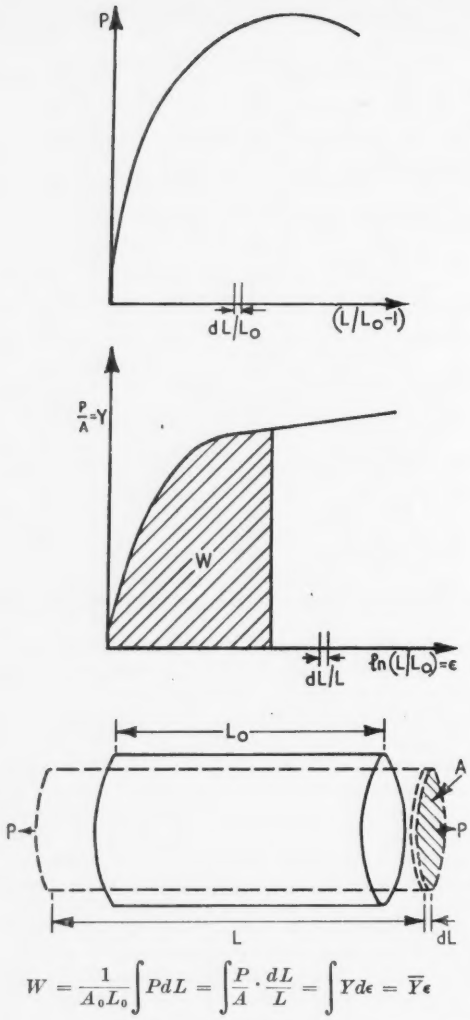


Fig. 8—Residual stresses in bars: effect of skin pass[10]

(Fig. 10*a*) the shortening of the free end of the work-piece is accompanied by free spreading in lateral directions (free, that is, if the tool is well lubricated); the resistance to deformation is as predicted by the stress/strain curve. In rolling wide strip (Fig. 10*b*) the compression is accompanied by free elongation in the direction of rolling, but lateral spread of the strip is inhibited by the unrolled metal. The effect is the same as if a constraining force were applied across the width of the strip, and in consequence of this the resistance to deformation is effectively raised by 15%. In the piercing operation (Fig. 10*c*) all spread is inhibited, and the resistance to deformation is raised by a factor of 3 or even more.

Generally speaking, this type of constraint depends on tool-stock configuration. Figure 11 shows how the two are related in the plane-strain indentation test, for tools which are narrower than the thickness of the work-piece.[15] Figure 12 shows the same effect for wire drawing (experiments) and sheet drawing (theory). The ordinate of this diagram represents the factor by which the yield stress must be multiplied for the purpose of calculating the die pressure.

Friction between tool and stock imposes a further constraint on deformation. As is well known, if the specimen in the compression test is not adequately lubricated, barrelling occurs, because friction inhibits the spread of the layers adjacent to the tool; it is perhaps less widely known that the compression load is raised in consequence. Since the constraint is least at the periphery of the surface of contact with the tool and greatest at its centre, the pressure is non-uniform, with a peak at the centre, as shown in Fig. 13. Now, the relative size of the pressure peak depends not only on the coefficient of friction but also on the tool-stock configuration. The reason for this is shown diagrammatically in Fig. 13. If the compression specimen is tall compared with its cross-section, the



$$W = \frac{1}{A_0 L_0}\int P dL = \int \frac{P}{A}\cdot\frac{dL}{L} = \int Y d\epsilon = \overline{Y}\epsilon$$

Fig. 9—Stress/strain curve

bulk of it will deform freely and the pressure peak will be small compared with the base. If, however, the compression specimen is more like a thin disc, the bulk of it is to be found in the layers adjacent to the tool face which are denied the freedom to spread. In this case the pressure peak will tower large over the base.

A similar state of affairs exists in rolling. Friction between roll and strip inhibits the free elongation of the strip and, in consequence, the pressure is raised towards the centre of the arc of contact. Figure 14 contains measurements of roll pressure, with characteristic pressure peaks, termed ' friction hills,' near the centre of the arc of contact.[16] The friction hill is small when rolling thick stock in light passes. It is large in the rolling of thin strip, and in this case it is further increased because the pressure flattens the rolls and thereby increases the arc of contact. If the strip, in addition to being thin, is also hard, a

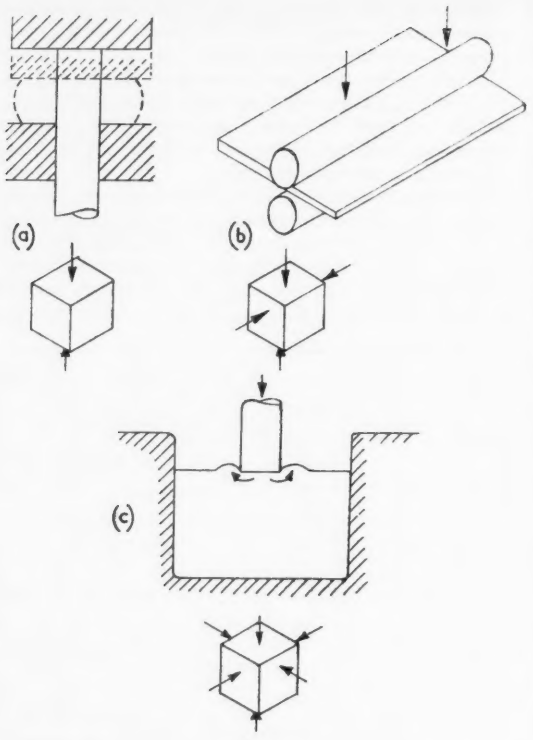


Fig. 10—Elastic constraint of deformation: (*a*) *Y*, (*b*) 1·15*Y*, (*c*) 3*Y*

situation sometimes arises where no further reduction is possible, because however much the rolls are screwed together, the additional force merely further flattens the rolls and never catches up with the increased resistance to deformation. The final stand in a tinplate mill works very close to this condition, and therefore the lubricant needs to be chosen carefully so as to keep the coefficient of friction as low as possible.

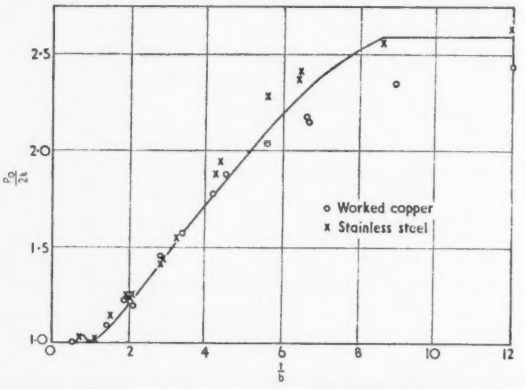


Fig. 11—Constraint factor in plane-strain indentation[15]

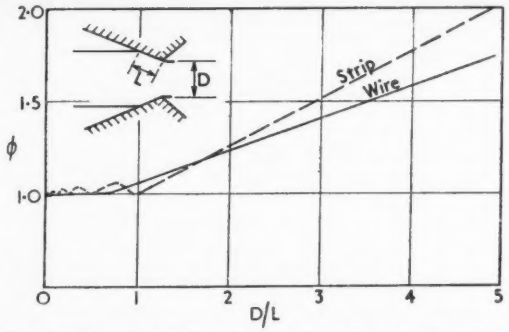


Fig. 12—Constraint factor in wire and sheet drawing[5]

The tool-stock configuration may be improved by reducing the size of rolls, so as to shorten the arc of contact between roll and strip. Figure 15 shows how the roll size affects the size of the friction hill.[17] Clearly, small rolls are beneficial, even if the limiting reduction has not yet been reached, because the rolling loads are smaller and therefore the mill may be made smaller. Figure 16 shows sketches of two mills designed to do the same job, but with greatly differing

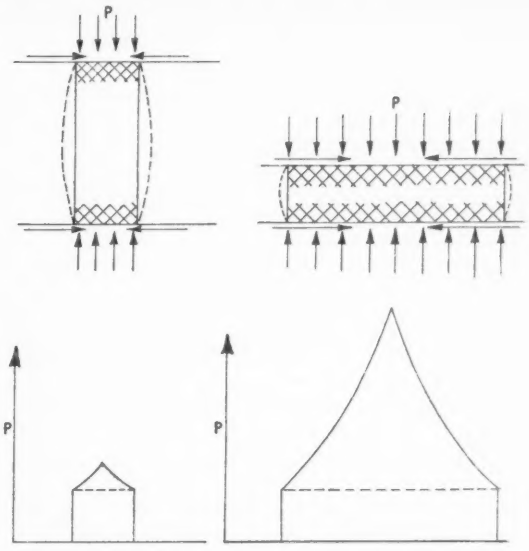


Fig. 13—Frictional constraint in compression test

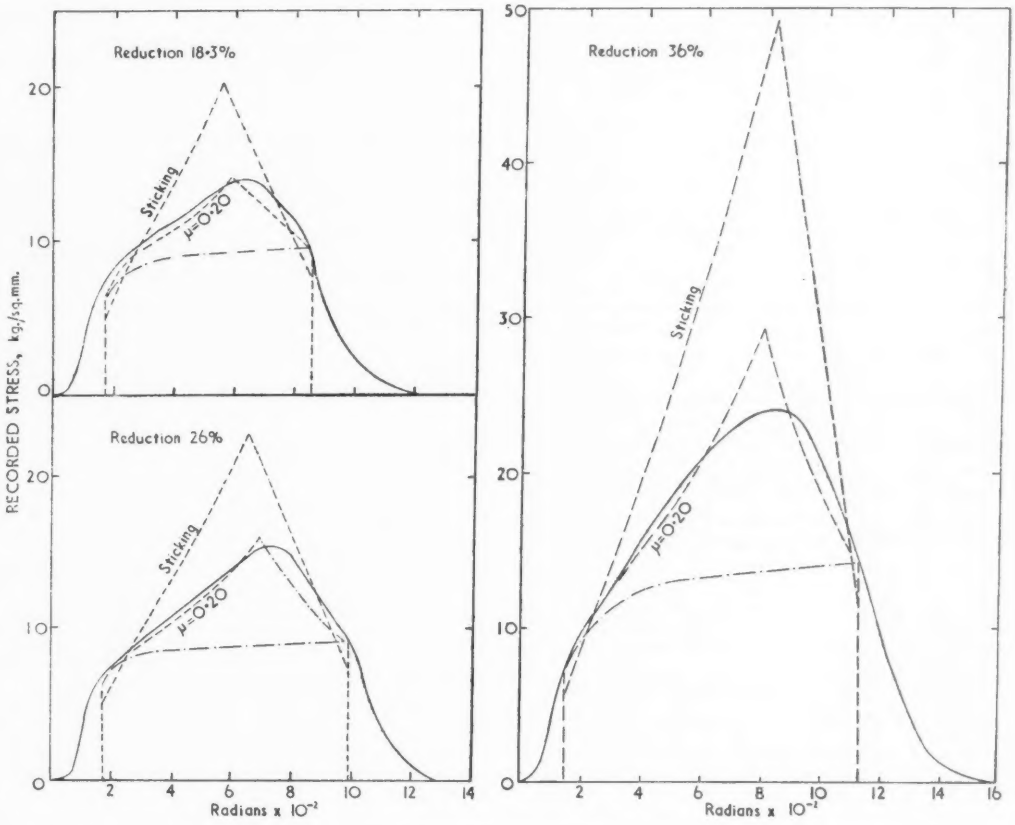


Fig. 14—Friction hill in rolling[16]

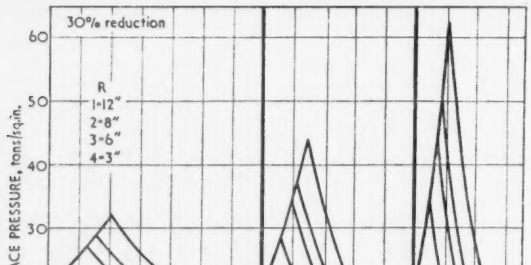


Fig. 15—Effect of roll diameter on friction hill[17]

roll sizes.[18] The contrast in plant size is the direct outcome of a change of tool-stock configuration.

HYDROSTATIC STRESSES

There is one other method of reducing rolling loads, by tension applied to the strip fore and aft, which leads to the question of hydrostatic stresses in metal working. Now, if a rolling mill could be run at the bottom of the ocean, the strip would deform in precisely the same way as it does on land, in spite of the tremendous change in ambient pressure. An eminent physicist has been sufficiently curious about the effect of hydrostatic pressure to go to the trouble of placing a miniature wire-drawing plant in an oil chamber and pumping the pressure up to 12,000 atm.[19] This experiment and many other investigations have confirmed that the plastic deformation of metals is unaffected by volumetric stresses, whether compressive or tensile. In consequence of this the general rule may be formulated that " plastic stress systems which differ only by a volumetric component produce identical deformation." This rule, which is symbolized in Fig. 17*a*, is of great practical value. As shown in Fig. 17*b*, it implies identity of extrusion and drawing, so that knowledge about one process may be applied to the other. For example, wire drawers found long ago that there is an optimum die angle for which the drawing force is least. Figure 18 confirms that this is also the case in extrusion.[20] Since in the cold extrusion of steel the tool pressure is often the limiting

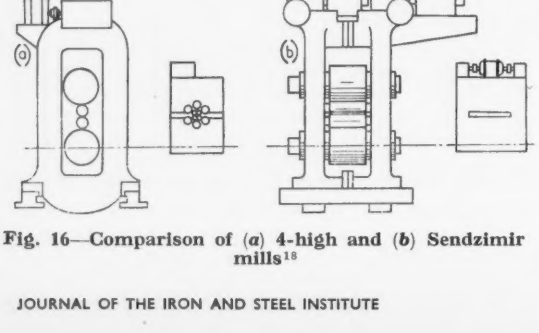
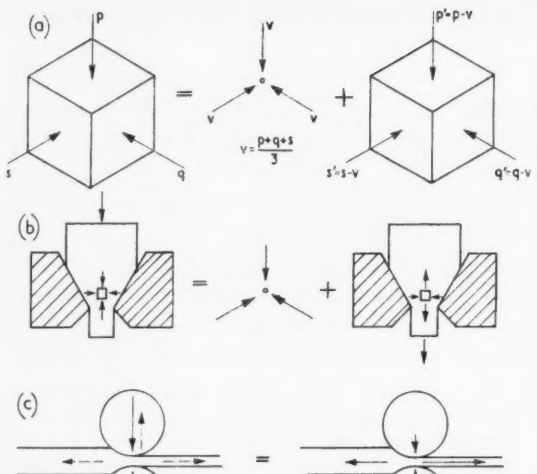


Fig. 16—Comparison of (*a*) 4-high and (*b*) Sendzimir mills[18]



(*a*) The stress rule
(*b*) Correspondence of extrusion and drawing
(*c*) Effect of tension on tool load in drawing and rolling

Fig. 17—Effect of hydrostatic stresses

factor, this effect merits close attention; an incorrectly chosen die angle may mean all the difference between a job being feasible or impossible to achieve. This rule also applies to the use of back and front tension in rolling, and of back pull in wire drawing. The reason why tension reduces roll and die pressures is made clear in Fig. 17*c*. By cutting down tool pressure less energy is wasted in friction, the stock is cooler, and the tools last longer.

The scope for tension is, however, limited, and in practice reliance is placed principally on pressure as a means of shaping metals. This is so because the

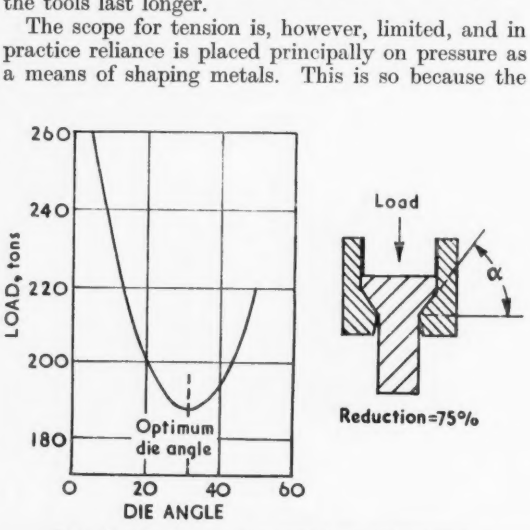


Fig. 18—Optimum die angle in extrusion[20]

rule just given tells only half the story. Although volumetric stresses are without influence on plastic deformation, they have a most pronounced effect on fracture: tension promotes it, compression suppresses it. Metallurgists are well aware of the disastrous effect on ductility of a deep notch in a tensile specimen, which is the outcome of a volumetric (triaxial) tension being set up in the waist of the specimen; it would be well if engineers were equally well aware of this fact. By contrast, volumetric compression delays the onset of fracture. Indeed, if the compression is sufficiently high, crystalline materials, which are normally brittle, behave in a ductile manner; for instance, rock salt, normally brittle, may be deformed as much as 50% with the help of volumetric pressure.[21] Equally remarkable effects of volumetric pressure on metals have been recorded by P. W. Bridgman. For instance, with pressures of the order of 16,000 atm. the reduction in area to fracture of a 0·45% C steel is about 90%, compared with 73% in the atmosphere. Even more spectacular improvements in ductility were achieved by raising the pressure to about 20,000 atm.

Ordinarily there may not be much advantage in making ductile metal more ductile at the cost of increased tool loads, but the idea of making a brittle material ductile sounds most attractive. For instance, cast iron, including the brittle whiteheart variety, may be forged and rolled, provided that the tools are designed to increase the compressive forces.[22] Another attractive possibility is to work ductile materials further than is possible by conventional methods in order to attain extreme strength by cold work rather than by alloying. For example, it is known that a high-carbon wire reaches an optimum strength at about a five-fold elongation and thereafter its mechanical properties deteriorate. By the time its original length has increased 14-fold it is so brittle that it cannot be drawn any more. If instead of being drawn this material is extruded, its strength increases continuously until its original length has been increased 200-fold.[23] This, indeed, is food for thought.

CONCLUSIONS

The first task which the scientist can usefully perform in support of his colleagues in the metal-working industry is to try to find concepts of general significance, with the help of which existing knowledge could be exploited more effectively and future progress planned more systematically. There is a great reservoir of knowledge in the industry, which is not used to the best advantage. There is, for instance, much scope for the exchange of experience between the ferrous and non-ferrous sides of the industry, because the laws concerning deformation and forces in metal working are the same whatever the metal. The magnitude of the tool loads is clearly of importance to the designer of metal-working machinery; whether the end product is acceptable to the customer or not depends not only on its dimensions but also on its physical properties. Rules such as those enunciated in the paper make it easier to retain more knowledge in the mind, and they encourage a more orderly approach to everyday problems. Trouble-shooting becomes easier and the work of development may be more clearly directed.

A dominant part is played in metal working by the concept of tool-stock configuration, by the idea of the stress/strain curve as a sort of 'identity card,' and by the notion of equivalent stress systems which differ only in the magnitude of the volumetric component. Naturally, these concepts do not exhaust the list—indeed, they refer to only two of the many aspects of the cold working of metals, i.e. to the mechanics of the processes and to the properties of the products. In practice, problems of lubrication, heat, and tool wear are often more important. Even so, these other problems cannot be tackled systematically without knowledge of the ideas outlined in the paper.

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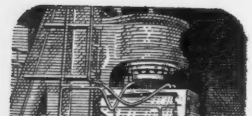

IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

Wire-Drawing Machines for Steel Wire

By H. Richards

SYNOPSIS

The paper is a survey of the types of wire-drawing machine in use in the United Kingdom for drawing steel wire, and compares U.K. practice with that in Europe and the U.S.A. Possible future developments towards increased speed and efficiency are outlined.

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THE MAKING OF WIRE is one of our most ancient arts. For generations it was produced by piercing a tapered hole in hard material and drawing short lengths of wire through the hole, originally by hand and subsequently on crude machines. The wire was lengthened as it was drawn through each hole, gradually decreasing in size until it work-hardened to the point where further elongation became impossible. It was annealed and the process was repeated until wire of the required diameter was produced.

Fundamentally, this method of making wire has not changed during hundreds of years. Today, it is produced tremendously more rapidly and in very large quantities, resulting from improvements in the dies through which it is drawn, the machines which use the dies, and the treatment given to the wire before and during the drawing operation. Probably the greatest single advance made in the drawing of wire since the very early days was the introduction about 25 years ago of dies made from tungsten carbide, which made possible the use of machines capable of drawing the wire normally used in industry at high speed and low cost.

Before the advent of the tungsten carbide die, the normal method of producing wire was to draw it through one die at a time starting from a coil of hot-rolled rod weighing 200 lb. or less. The wire-drawer shaped the holes in the dies himself and drew the wire on a simple machine which coiled it on a tapered drum. The dies consisted of steel plates punched with a series of tapered holes. These holes were trimmed to size by the wire-drawer using a tapered punch; this job demanded a great deal of skill and knowledge about the reduction in area to be given to the wire through each succeeding die. It was also hard work, because the holes in the die plate usually gave out after a coil or two had been drawn and required re-sizing; in addition the wire-drawer had to manhandle the coil of wire drawn on the machine, putting it back on to the carrier from which it was originally drawn ready to be drawn again to the next smaller size. One man could attend a number of machines and kept several coils running at the same time. In those days, the wire-drawer had to be a skilled man and was rewarded as such.

This paper was presented at the 27th Meeting of the Iron and Steel Engineers Group, held at 4 Grovenor Gardens, London, S.W.1, on 9th December, 1954. A full report of the meeting will be published in a later issue of the *Journal*.

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Through the years it became known how much reduction various kinds of wire could stand between successive drafts, and the dimensions at these points had a great deal to do with the fixing of the standard wire gauges of today.

All this has now changed, chiefly owing to the remarkable resistance to wear offered by the modern tungsten carbide die. The wire-drawer no longer has anything to do with the shaping and sizing of the die, and from his point of view practically all the skill has been taken out of his job; today only a few of the old-type skilled wire-drawers are needed for drawing shaped wires or other special jobs for which the tungsten carbide die is not yet an economical proposition.

The tungsten carbide die also made it possible to draw long lengths of wire without appreciable increase in size of the hole; consequently, the coils of hot-rolled rod could be welded together, avoiding the need to stop drawing at the end of each coil and start again on another one. In turn, this made possible the use of a machine drawing through a number of successive dies at once, which reduced the speed of the ingoing wire and made possible a greatly increased speed through the final die.

TYPES OF MACHINE

The design of practically all wire-drawing machines is based on the use of power-driven capstans, which haul the wire through the dies. The speed of the capstans is progressively increased to match the elongation of the wire as it is drawn through successive dies.

The machines can be split into two groups, one of which uses capstans running at exactly the same speed as the wire being drawn by them (' non-slip ' machines), and the other capstans which run faster than the wire (' slip ' machines). These terms relate to circumferential slip only. On all wire machines (except some special types) the wire skids longitudinally on the capstans, the amount of skidding depending upon the number of turns taken round the capstan.

The use of ' slip ' or ' non-slip ' machines depends upon the method of lubricating the wire as it passes through the dies. If a plastic or non-liquid lubricant is used, such as dry soap, wax, tallow, thick grease, or graphite, this is termed ' dry drawing ' and is done on non-slip machines. If lubrication of the dies is by a liquid, such as soap solution, oil, soluble oil, or water, this is called ' wet drawing ' and is done on slip machines. Apart from a very few special cases, these terms hold good for all the wire that is drawn.

Broadly speaking, ferrous wires require lubrication by the dry method and are drawn on non-slip machines. Non-ferrous wires are practically all drawn by the wet method on slip machines. Lubricants for dry drawing are applied to the wire as coatings, which are squeezed tightly on the wire as it passes through the first die, the surface of the wire being prepared to enable the lubricant to adhere more readily to it. Lubricant is also provided at each subsequent die, but if the coating put on by passage through the first die is destroyed it cannot be renewed at the following dies and rapid die wear takes place. This is why non-slip machines are used for dry drawing, to avoid destruction of the very thin coating of lubricant put on at the first die by the wire slipping on the capstans.

Liquid lubricants do not have this disadvantage and, in addition, can lubricate the wire as it skids around the capstans on slip machines. It can also be renewed easily at each die. The wire and dies can be more easily cooled on wet-drawing machines, and so machines of this type operate at the highest speeds.

It is not possible to discuss all the normal types of wire-drawing machines in the space available, and so the paper deals with some machines used in the production of steel wire.

Single-Die Machines

On machines requiring only one die, the capstan takes the form of a long tapered drum mounted on a vertical or horizontal shaft (usually vertical). The wire coming through the die impinges on a radius at the bottom of the drum, causing a wedging action, so that each turn wound on at the bottom of the radius pushes preceding turns out of the way, shuffling them up the capstan in an orderly manner and producing a coil of wire which is not tangled in any way when lifted off the capstan in the form of a bundle. The radius at the root of the capstan and the taper from bottom to top are important and must bear a proper relation to the diameter of the drawn wire, the diameter of the formed coil, and the ultimate weight of the finished bundle. A drawing capstan used in this manner and forming a collector for a finished coil is called a ' block.'

To adjust the diameter of the finished coil and to ensure that all the turns when drawn will automatically be in the same plane, provision has to be made to adjust the axis of the die in relation to the axis of the wire being drawn through it. Owing to the difficulty of producing a die with an exactly round hole and with a completely uniform contour over the whole of its working length, the stresses in the drawn wire are not always equal all round its circumference. This can produce wire which is not straight even if pulled in a straight line through the die. Also, as it is necessary to persuade the wire to coil itself to a required diameter after being drawn, a certain amount of off-set must be given to the die, sufficient to cause the wire to coil naturally in a circle slightly greater in diameter than the diameter of the block. Provision must be made to enable the die to be set to produce this condition, which is known as ' cast.' To make this die adjustment correctly to suit wire of various sizes and materials, widely differing in tensile strength and drawn in various sizes of coils, is one of the few remaining skills required of the wire-drawer. To facilitate removal of the coil of wire from the block, it is fitted with a collapsible stripper operated by a power hoist. The machines used to draw wire through a single die are called ' bull blocks.'

Multiple-Die Machines

Machines of a similar type are often used to draw wire through two dies; on these machines the block

has underneath it an additional capstan which draws the wire through the first die. Its circumference is smaller than that of the upper capstan by an amount equal to the elongation of the wire between the first and second die. If the elongation of the wire is less than the difference in circumference between the two capstans, the wire cannot be drawn. If it is greater, the wire will slip on the lower capstan, which is not desirable should the slip exceed more than about 2%, as it gives rise to rapid wear of the smaller capstan, by abrasion of the wire which is constantly slipping around it. A machine of this type is therefore limited in its application and can only be used for a fixed reduction in area between the first and second die. It is, however, a cheap way of providing a two-die machine and is much used when large quantities of the same class of wire need drawing through two dies to its finished size. A two-die bull block is termed a 'double-deck block.'

Sometimes when thick wire needs to be drawn through more than one die, a number of bull blocks are arranged to be coupled together so that they can be used as a team or as individual units as required. Each block is driven by a variable-speed D.C. motor with suitable control gear arranged to permit individual operation of each motor, and also to tie them together so that, having set the speed of the final one, the speed of the others is controlled by jockey pulleys operated by the wire, the position of the jockeys depending upon the wire tension between each block. The jockey pulleys in turn operate rheostats controlling the motors. Field forcing is used to give very rapid response to any movement of the jockey pulleys, and the motors have a characteristic to permit hunting. Provision is made to adjust the dynamic braking on each motor so as to provide for a bias towards the block running at the highest speed. This arrangement of bull blocks is commonly used, but it has the disadvantage that thick wire running around pulleys is not altogether an ideal arrangement and very substantial guarding is necessary to avoid danger should the wire break.

For handling thinner wire from an entering size not more than about $\frac{5}{16}$ in. dia. requiring to be drawn through a number of dies at once, a series of bull blocks can be coupled together in a way which does not require accurate relative speed regulation between each capstan. Each block is made to run at a speed a little higher than would be necessary to supply exactly the amount of wire called for by its succeeding block, so that the amount on each block slowly accumulates. Each block is, in fact, a separate machine drawing wire through a die and coiling it up. By an ingenious device commonly called a 'waffle arm,' wire can be picked up from the running block and transferred to its succeeding block, where it is drawn and coiled through the next die in the series, and so on until the final block is reached.

This type of machine has the great advantage that a wide variation of die reductions can be used on it without the need for complicated and expensive gear automatically controlling the speed through each die to line up exactly with the elongation of the wire passing through it.

When the accumulation of wire on any block becomes too great, this block and all the preceding blocks are stopped and not started again until the excess wire has been drawn from it by its succeeding block, when it is again started. To make this type of machine very flexible and easy to operate, it is often fitted with a variable-speed drive to each unit by means of a variable-speed D.C. motor, hydraulic motor, or other means; the only interconnection between the units is a means to ensure that when any block is stopped, all preceding ones also stop whilst succeeding ones continue to run. This is necessary to prevent the wire being twisted by the action of the waffle arm until it breaks through torsion.

The waffle arm acts like a finger picking the wire off a block, turn by turn, when it is carried over an overhead guide pulley and from here over another guide pulley on to the following die. This method of transferring wire from one block to another puts a twist in it of 360° for each revolution of the waffle arm round the block. This does not harm the wire provided that it is running fast enough for the 360° twist to be distributed over a length of several feet. If the wire is stationary, however, and continues to be twisted, it is not long before the length of wire between the waffle arm and the overhead pulley (usually about 3 ft.) is twisted until it breaks, thus making it necessary to provide means on this type of machine to prevent a block running when the one succeeding it is stopped. Automatic devices are provided on most modern machines of this type to give sequence stopping in front of all the blocks. These machines are termed 'accumulation machines' and are in very general use throughout the wire industry. However, they suffer from a few disadvantages. They cannot easily be operated when wire exceeding about $\frac{5}{16}$ in. diameter is fed into them—particularly when the wire has a high tensile strength to start with, owing to the difficulty of manipulating this stiff wire over a number of comparatively small pulleys. They take a long time to thread up before they can produce the finished wire on the last block owing to the quite considerable amount of wire carried on each block. They are not satisfactory at finishing speeds in excess of about 2500 ft./min., owing to the difficulty of unwinding the wire turn by turn from each block by the waffling apparatus, and lastly, they are a little dangerous should the wire break whilst running at a high speed.

In spite of these disadvantages, it is safe to say that by far the largest number of machines drawing ferrous wire in the U.K. and throughout the world are of this type, with one notable exception—the U.S.A., where for a number of years the accumulation machine has given pride of place to another type.

U.S. Machines

This machine operates in the same way as the coupled bull blocks previously mentioned. A capstan pulls the wire through each die and coils it up, but in this case without any accumulation. The capstans are coupled together electrically, each being driven by a variable-speed D.C. motor and controlled by a jockey

pulley operated by the running wire, so that each preceding block feeds the correct length of wire called for by its successor. Only a few turns of wire are carried on each capstan and it runs directly to the following capstan round a jockey pulley and a guide pulley; it is not uncoiled from the top of the block by a waffle arm and so it is not subjected to any twisting whatever.

The design of the electrical control to maintain correct relative capstan speeds is not easy, particularly during acceleration and deceleration, both of which must be rapid to assist production. Also, unless care is taken to provide very rapid regulation of the motors, hunting is liable to occur, and much of this cannot be tolerated because the available time for correction is very small, owing to the limitations of movement allowable at the jockey pulleys.

The percentage speed difference between the blocks is, of course, equal to the percentage of elongation of the wire between each die for any particular set of dies which may be in use. It is expected of the machines that they should cover a range of die reductions from about 40% when drawing mild steel to about 22½% when drawing high-carbon steel; therefore the normal percentage speed difference when all the driving motors are running at equal speeds is fixed at about 33%. Under certain running conditions on a machine which may have up to ten capstans, the motor speeds can vary widely from one end of the machine to the other. Unlike tandem strip-rolling mills, where only two or three motors have to keep in step and where the strength of the rolled strip can be used to quite an appreciable extent to assist in giving equal acceleration and deceleration, the strength of the wire is very much less in relation to the size and number of the motors required to accelerate together. Consequently, the control of acceleration of all the motors simultaneously is rather difficult and, in fact, does not always happen; some slipping of the wire on the capstans can occur during starting and stopping, causing trouble by wearing grooves in the capstans.

This type of machine has advantages over the accumulation type in that it can deal with a slightly thicker inlet wire. The pulleys are larger and the wire is always under more tension; also there is no twisting. It can be threaded up and produce wire much more quickly, as there is no time lost waiting for each capstan to fill with hundreds of turns of wire. It is happier at high speeds and is certainly safer to operate. On the other hand, it requires variable-speed constant-horsepower D.C. motors, it is not so flexible in its range of production, and it requires more intelligence to operate efficiently.

The main reason for its apparent inability to oust its rival on this side of the Atlantic is probably its higher capital cost and the wider range of finished sizes which can be produced on the accumulation machine. The requirement of direct current is also undoubtedly a handicap in Europe.

Although this type of machine can handle thicker wires more easily than the accumulation type, it still suffers from the disadvantage of having numerous pulleys over which the wire must pass. For this reason, both types of machine are difficult to operate if an ingoing wire of much more than $\frac{5}{16}$ in. dia. is being drawn, particularly if the wire is of the high-tensile variety.

In recent years there has been an increasing demand for larger sizes of high-tensile wire which, to attain the required tensile strength by cold-working, must be drawn through several dies from inlet sizes up to ½ in. dia. or more. The demand and the increased wages now paid to operators required a change from the old method of drawing this kind of wire—one die at a time on slow-speed single-die machines.

Reactive Drawing

This need has been met by the introduction during the last few years of a type of multi-die machine which requires no pulleys round which thick wire must be bent, no accumulation on the blocks (and therefore no twisting of the wire), and with provision to put sufficient pull on the wire between the drawing capstans to pull it straight under considerable tension before it enters the dies. This machine was originally developed, not with the object of drawing thick wire, but to obtain the advantages which it was supposed would result if considerable tension could be put on a running wire before it entered the die.

This method of drawing is known as ' reactive ' or ' back-pull ' drawing. From a purely theoretical point of view, wire drawn in this way should reduce the die wear, the amount of heat generated in the dies and wire, and the power required. Laboratory experiments and calculations of the stresses on the wire and dies during drawing made it appear that the advent of a reactive drawing machine would be of great benefit to the industry. When at last a production machine was made that was capable of working on the reactive principle it was a disappointment to find that these benefits were not forthcoming, at least not to the extent anticipated.

It was overlooked that, during years of endeavour, the wire industry had found out by trial and error the maximum amount of die reduction the average wire would stand, taking into account the occasional weak spots which are always present and the need to handle welds whilst keeping wire-drawing machines running without an undue proportion of wire breaks—in short they had found the maximum pulls that could be ' economically ' applied. Unfortunately, back-pull drawing means what it says, and any back pull desired must be added to the forward pull for any given reduction in area in the die. As the forward pull could not be reduced without upsetting the normal procedures of the trade and was already near the economical limit, and as the wire has also to act to some extent as a coupling between the capstans, particularly during acceleration and deceleration, the additional back pull which could be safely applied was insufficient to do more than give an indication that the theories were correct. It could not be applied to anything like the extent required as any slight defects in the wire, which normally give no trouble, and welds, which normally give quite a little trouble, caused an increase in the number of breaks when subjected to the extra load imposed by substantial back pull.

On some classes of wire, such as shaped wire, where

it is impossible to attempt a reduction in area of more than 10% or 15%, back pull can be very beneficial, as it prolongs the life of the expensive shaped dies. Also, when drawing wire such as stainless steel, which has a bad tendency to scratch and pull out the dies heavy back pull is useful, as it assists die lubrication; here die reductions can be reduced to permit plenty of back pull and still be economic owing to the relatively high price of this wire. However, these remarks do not apply to the general run of mild steel and high-carbon steel wire production, which is the backbone of the industry.

It appears, therefore, that the theoretical advantages allied to reactive drawing are not yet attainable. If hot-rolled rods could be produced without the occasional fin or foreign matter rolled in, in coil weights of 4000 lb. instead of 400 lb., the hazard of the weld and the break ' for no reason at all ' would nearly become things of the past. If the habit of using die reductions which stress the wire too near its breaking point could be changed, and the 4000-lb. piece could be wound on a spool instead of being tangled up in a coil, reactive drawing might be used to a worthwhile extent; if not, there would still be benefits in many other directions. In the meantime slow progress is in fact being made.

In present practice, the back pull applied, except in a few special cases, is no more than is necessary to ensure a reasonably tight and straight wire between the capstans—in fact, no more than is applied by the jockey pulleys in the machine previously described. In addition, it can handle thick wire that cannot be drawn satisfactorily on any of the other types of machine mentioned.

In this machine the drawing capstans are individually driven by D.C. motors electrically coupled to permit them to give controlled torque as required to pull the wire through each die. Each motor helps the preceding one to an extent depending on its torque setting. The last motor fixes the drawing speed, which can be varied, usually over a range of about 2–1, giving constant horsepower over this range. The speed of the motors other than the final motor is not controlled directly; it automatically adjusts itself so that the torque is maintained, keeping the wire under tension between each capstan.

Whilst the machine is being threaded up, the torque developed by each motor is adjusted until it is just sufficient to pull the wire through the die and in addition to provide a little extra pull through the wire itself to assist in turning the preceding capstan. This extra pull is back pull, ensuring that the wire passes straight into each die, which is an important consideration, especially when drawing thick wires.

To assist still further in avoiding any deviation from straightness in the wire as it passes through the die from one capstan to the next, the capstans are tilted in the direction of drawing to enable a substantial number of turns to be taken around each one and to permit the wire to run through the die to the bottom of the following one in a straight line. This tilting of the capstans does not entail any mechanical complication. Each one is driven through a worm gear; instead of the worm-wheel lying in a horizontal plane it is turned through a few degrees round the worm in an inclined mounting.

OPERATION

All types of multi-die non-slip machine are now built to run at the highest speeds at which it has been found possible for them to produce good-quality wire. To satisfy the requirements of the industry they are made to work with a reduction in area per die varying between 30% and 40% for drawing low-carbon wire and between 20% and 30% for high-carbon rope wire and spring wire. These reductions are based mainly on tradition. Speeds were formerly so low that the wire could be given the heaviest reductions it could economically stand without much trouble arising from heat generated in the die and wire. Today, speed of drawing, particularly with high-tensile steel, cannot be increased owing to heat destroying the die lubricant or spoiling the wire quality, or both. To reduce this difficulty, pains are taken to water-cool the die and the capstans adequately; in addition, on some machines large quantities of air are blown on the wire whilst it is on the capstans to take away as much heat as possible between each die to keep down the final temperature of the wire and to maintain its quality.

It is difficult to see how much more efficient cooling could be obtained, but it is not difficult to reduce the reduction in area at each die, which might prevent overheating of the lubricant film and give more opportunity to extract the heat from the wire, which in turn would permit increased speeds and higher outputs per operator. The greater margin between die pull and the breaking strength of the wire might also permit back pull to a sufficient extent for benefit to be derived from its theoretical advantages. Unfortunately, a machine with more dies costs more money but nevertheless a determined step in this direction might result in a lower cost per ton of finished wire produced.

Increased Efficiency

Another way to reduce the cost of wire is to increase the operating efficiency of the machine, by eliminating as many stops as possible. Until recently, practically all the tonnage of steel wire made was produced in small coils. The average weight of the finished coils was about 200 lb. and the shortest stopping time to take off a finished coil and restart the machine was about $\frac{1}{2}$ min. (usually much longer). In thick wire much heavier coils are now produced, but thinner wires cannot be coiled in heavy weights on a rapidly rotating block because they so easily become tangled and make a lot of scrap. To assist in this direction, a continuous coiler is now being increasingly used. On this machine, which can be attached to a normal wire-drawing machine or built in with it, the wire is wrapped round a stationary horizontal block and shuffles forward continuously in a form of a stationary coil of ever-increasing weight. When sufficient has been accumulated, it can be cut off and removed without stopping the machine, leading to a substantial improvement in operating efficiency. A difficulty with this mechanism is that a twist is put into the wire as each turn is wound on the block, and so it is

necessary to take the wire through a series of staggered rollers (called ' killing rolls '), which straighten it out so that it can be properly ' cast ' in the finished coil. The next step is to introduce a die instead of the straightening rolls; this is now being done, but to water-cool this die and also supply it with lubricant is not an easy mechanical problem. For the production of wire for shipment to customers, the continuous coiler is rapidly gaining ground, particularly on the Continent.

Spools

Another way to keep the machine running is to wind the finished wire on spools. The copper-wire industry has led the way here; practically all the copper wire drawn today in modern plants is put on spools. They have been compelled to do this because it is impossible to draw in coils of any weight at speeds of 5000–8000 ft./min. which are now quite usual. To date, steel wire is not drawn at anything like these speeds, but the steel industry may very likely have to follow the copper industry, and for the same reason.

A spool is the best kind of container on which to draw wire at a high speed. It is also the best way to store it without waste, as it takes up a minimum amount of space. However, spools are rather expensive and are easily damaged if used for transporting wire outside a factory. For use inside a factory for wire processing such as patenting, galvanizing, or re-drawing, and also to feed straightening machines, nail-making machines, etc., the spool is ideal.

Spooling machines can be roughly divided into two types. On one the speed of the spool is mechanically controlled throughout the filling of the spool in such a way that the surface speed of the wire remains constant, the spool being slowed down gradually as each layer of wire is added. This type of spooler is mechanically complicated and requires to be very accurately adjusted to work properly. It is also difficult to arrange for sufficient torque to spool thick wires at sufficient tension. The other type relies upon putting sufficient torque into the spool whilst it is running to ensure tension in the wire. As the spool fills, the torque on its driving shaft increases, causing the spool to be gradually slowed down. On heavy spoolers the driving torque is usually provided by a D.C. motor, on medium-sized machines by an A.C. torque motor, and on small machines by an adjustable permanent-magnet eddy-current drive.

An interesting spooler for medium-sized wire is the differential type. This machine comprises a differential gear especially designed to run with as little friction as possible. The outer member of the differential is driven directly by the wire-drawing machine so that it keeps in step with it all the time. It is driven at the same speed as the empty spool. One half-shaft from the differential carries the spool, and the other carries a flywheel arranged to have approximately equal angular momentum to the spool when the spool is full.

When the machine starts, the spool, having much less inertia than the flywheel, tries to run faster and puts the necessary tension in the wire. As the spool fills, the torque on its half-shaft slowly increases owing to the increase in diameter. This torque is also building up slowly in the half-shaft carrying the flywheel, causing it to speed up whilst the spool slows down. When the wire-drawing machine is stopped, the differential casing is also compelled to stop, when the energy in the rotating flywheel stops the spool without putting any extra pull in the wire.

Spooling machines are in regular use winding wires from 0·0006 in. dia. on spools weighing a few ounces up to wires 0·625 in. dia. on spools carrying several tons and running at speeds from a few hundred to 10,000 ft./min.

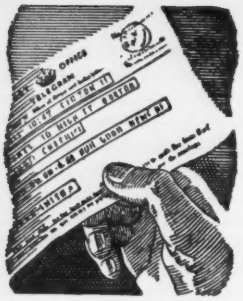
Use of Slip Machines

The slip type of machine is not used very much in the ferrous wire industry, and only when fine wires are required. These machines operate on the wet-drawing principle using liquid lubricants. Practically all steel wire down to about 25 S.W.G. (0·020 in. dia.) is dry-drawn on non-slip machines; below this the wet-drawing slip machine begins to compete and shares the production down to about 0·006 in. dia., below which practically all wire, both ferrous and non-ferrous, is wet-drawn.

The wet-drawing machine uses capstans to draw the wire through the dies, but no attempt is made to align the speed of these capstans exactly to match the speed of the wire. They are driven faster than the wire, which skids on them, relying upon the lubricating qualities of the drawing liquor and the surface hardness of the capstans to avoid undue abrasion and wear. Only two or three turns of wire are taken round each drawing capstan, the final tension being sufficient to maintain a reasonably tight wire through the machine; consequently, they operate with varying degrees of back pull which cannot be under much control. For this reason, the reduction in area per die is less than that normally used on non-slip machines to give a reasonable margin between die pull and wire breaking load so as to avoid wire breaks, which are expensive.

More dies and more capstans are required, but this does not matter much on slip machines. It does not increase their cost to any appreciable extent as the capstans are grouped together on shafts each carrying four or five. To provide the necessary circumferential speed difference to line up approximately with the die elongation, the capstans on each shaft are arranged in diameter steps. Unfortunately, the thickest end of the wire must pass over the smallest steps, as these are the ones with the slowest surface speed; many of the troubles met with on these machines are due to this difficulty.

It is possible to overcome this stepped capstan trouble by making the capstans all the same size, but this increases the cost of the machine to a point where considerable courage is needed to use it in place of a dry-drawing machine. There is an old saying in the wire industry which dies hard—"*Never draw wet if you can draw dry.*" However, large slip machines are now in use to a limited extent, taking advantage of the reduction in heat by using a smaller than usual reduction in area per die, and submerging the whole of the dies and the lower portion of the capstans in the drawing liquor to permit high drawing speeds without any sacrifice of wire quality.



N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Joint Metallurgical Societies' Meeting in Europe, 1955

Preliminary details of the Joint Metallurgical Societies' Meeting in Europe were given in the News Section of the December, 1954, issue of the *Journal*, p. 396. A circular, C.786, has been sent to all Members of The Iron and Steel Institute and The Institute of Metals, and this includes the programme in Great Britain, Germany, Belgium, and France.

The following are details of the meetings to be held at Church House, Westminster, London, S.W.1, on Wednesday and Thursday, 1st and 2nd June:

Wednesday, 1st June

Afternoon—Opening Plenary Session. Speeches of welcome by the Presidents of The Iron and Steel Institute and The Institute of Metals, and replies by the Presidents of the American Society of Mining and Metallurgical Engineers and the American Society for Metals.

Inaugural Lecture on "*X-Ray Analysis and the Structure of Metals*," by Sir Lawrence Bragg, O.B.E., M.C., F.R.S., Fullerian Professor of Chemistry and Director of the Laboratories of the Royal Institution of Great Britain.

Thursday, 2nd June

Morning—Meetings of six simultaneous Technical Discussion Groups devoted to:

A. Ore Preparation and Beneficiation
B. Steelmaking: Basic Open-Hearth Furnace Design and Operation
C. Melting and Casting Techniques in the Non-Ferrous Metals Industries
D. Continuous Casting, Ferrous and Non-Ferrous
E. High-Temperature Alloys
F. Education and Training

Afternoon—Meetings of six simultaneous Technical Discussion Groups devoted to:

G. Iron and Steelmaking. Desulphurizing and Desiliconizing
H. Steelmaking: The Electric Arc Furnace for Tonnage Steel Manufacture
I. Production of Steel Strip and Sheet
J. High-Speed Wire Drawing
K. Rate Processes in Metallurgy
KK. Heat-Treatment of Special Alloys

Friday, 3rd June

Morning—Meetings of six simultaneous Technical Discussion Groups devoted to:

L. Physical Chemistry of Steelmaking
M. Production of Steel Ingots of High Quality
N. Production of Metals of High Purity
O. Extrusion of Ferrous and Non-Ferrous Metals
P. Fracture of Metals
PP. Heat-Treatment of Forgings

A more detailed programme of the Section of the Meeting in Great Britain and of the Sections in Germany, Belgium, and France will be published in the June, 1955, issue of the *Journal*.

Special Meeting in Scunthorpe, 1955

At the invitation of the Lincolnshire Iron and Steel Institute, a Special Meeting of The Iron and Steel Institute will be held in Scunthorpe from **Wednesday to Friday, 12th to 14th October, 1955.** The Institute will assist in obtaining hotel accommodation in Scunthorpe, Barnby Moor, Doncaster, Lincoln, and other places in the district, for the nights of Tuesday, 11th October, to Thursday, 13th October, inclusive. Transport will be provided when necessary. Proposals will be made known later.

The provisional *Programme of Technical Discussions and Works Visits* is as follows:

Wednesday, 12th October

10.0–10.30 A.M.—Formal opening of the Meeting in Scunthorpe

10.30 A.M.–12.30 P.M.—Presentation and discussion of the following papers (there may be changes in the titles, and in some cases the papers will be written jointly by those mentioned and others):

"*Developments in Ironmaking at Appleby-Frodingham*," by G. D. Elliot, O.B.E. (Appleby-Frodingham Steel Co.)

"*The Expansion Scheme of John Lysaght's Scunthorpe Works Ltd.*," by W. L. James (John Lysaght's Scunthorpe Works Ltd.)

12.30–5.30 P.M.—Alternative visits to: (1) 'Seraphim' (blast-furnaces, sinter plant, ore preparation) of the Appleby-Frodingham Steel Co.; (2) Normanby Park Works of John Lysaght's Scunthorpe Works Ltd.; (3) Iron Ore Mines of The United Steel Companies Ltd.

Members will be entertained to lunch in Scunthorpe in groups by the Companies and to tea at the works.

Thursday, 13th October

10.0 A.M.–12.30 P.M.—Presentation and discussion of papers in Scunthorpe in two simultaneous Sessions:

SESSION A

"*Steelmaking at the Redbourn Works of Richard Thomas and Baldwins Ltd.*," by S. R. Isaac (Richard Thomas and Baldwins Ltd.)

"*Organization for Maintenance*," by J. L. Gaskell (Appleby-Frodingham Steel Co.)

SESSION B

"*Underground Mining of the Frodingham Ironstone Bed at the Dragonby Mines, Scunthorpe*," by Clifford Smith (The United Steel Companies Ltd.)

" *Development of Chemical Methods for the Treatment of Low-Grade Ores at Appleby-Frodingham*," by L. Reeve (Appleby-Frodingham Steel Co.)

12.30–5.30 P.M.—Alternative visits to: (4) ' Seraphim ' *see* (1) above; (5) Redbourn Works of Richard Thomas and Baldwins Ltd.; (6) Steel Foundry of Thos. Firth and John Brown Ltd.

Members will be entertained to lunch in Scunthorpe in groups by the Companies and to tea at the works.

Friday, 14th October

10.0 A.M.–12.30 P.M.—Alternative visits to: (7) Melting Shop and Rolling Mills of the Appleby-Frodingham Steel Co.; (8)–(12) repeat of previous visits (1)–(3), (5), and (6) above.

Members and Ladies will be entertained to lunch in groups in Scunthorpe by the Companies.

Ladies' Programme

Ladies are cordially invited. A Ladies' Committee is preparing an attractive programme, which will include visits to Lincoln and to other places of historical interest and natural beauty. Ladies will also be given opportunities of visiting the iron and steelworks.

Social Functions

Members and Ladies will be entertained by the Lincolnshire Iron and Steel Institute and the Mayor and Corporation of Scunthorpe at parties on the evenings of Wednesday and Thursday, 12th and 13th October. Details will be announced later.

Autumn General Meeting, 1955

The **Autumn General Meeting** of The Iron and Steel Institute will be held on **Wednesday and Thursday, 16th and 17th November, 1955.** Full details of the programme will be given in a later issue of the *Journal*.

Annual General Meeting, 1956

Provisional arrangements have been made to hold the **Annual General Meeting** next year, in London, on **Wednesday and Thursday, 16th and 17th May, 1956.** The Members' Dinner will be held on the evening of Wednesday, 16th May.

NEWS OF MEMBERS

▶ Professor B. L. AVERBACH has been appointed Associate Professor of Metallurgy at the Massachusetts Institute of Technology.

▶ Mr. R. BUTCHER has left The United Steel Companies Ltd., and has joined the Development and Research Department of the Mond Nickel Co., Ltd., in London.

▶ Mr. S. K. CHOUDHARY has joined the Directorate of Inspection (Metallurgical), Government of India, at Burnpur, W. Bengal.

▶ Professor A. H. COTTRELL, of the Department of Metallurgy, University of Birmingham, has been elected a Fellow of the Royal Society.

▶ Mr. H. R. CURNICK has been appointed Works Manager of the Vaal Works of the Union Steel Corporation (of South Africa) Ltd.

▶ Mr. J. H. EVANS has been appointed Chief Metallurgist to British Timken Ltd.

▶ Mr. C. E. MAVROCORDATOS has left the U.K. for South Africa where he has been appointed Senior Lecturer in Metallurgy at the University of Witwatersrand, Johannesburg.

▶ Mr. E. PAGETT, Works Manager of the Forging Department of N. Hingley and Sons, Ltd., has been appointed General Manager of the Forgings Division.

▶ Mr. J. E. SRAWLEY has left the Meehanite Metal Corporation, New York, and is now Standards Engineer in the Corporate Sales Division of the Arwood Precision Casting Corporation, New York.

▶ Mr. J. G. WIDDOWSON has been appointed Managing Director of the Neepsend Steel and Tool Corporation.

▶ Mr. K. H. WRIGHT has resigned his position as Technical Director of Midland Rollmakers Ltd., Crewe, to take up the appointment of Director (Sales Management and Technical) with the Foundry Section of Johnsons Iron and Steel Co., Ltd., West Bromwich.

Obituary

Señor LUIS BARRIERO of Bilbao, Spain, in February, 1955.

Mr. O. I. VOLD, formerly Managing Director of A/S Norsk Blikkvalseverk, Simonsvik, Norway, on 6th December, 1954.

Mr. JAMES WAITE, of North Adelaide, S. Australia, on 2nd September, 1954.

CONTRIBUTORS TO THE JOURNAL

Arthur Conway, B.Sc.(Eng.), A.C.G.I., A.M.I.Mech.E.—Senior Scientific Officer in the Mechanical Section of the Plant Engineering Division, British Iron and Steel Research Association.

Mr. Conway served an apprenticeship with the De Havilland Aircraft Co., Ltd. He studied mechanical engineering at the Imperial College of Science and Technology and was awarded the degree of B.Sc.(Eng.) in 1952.

Comdr. (E) John Ivor Tennant Green, O.B.E., R.N. (Ret.), M.I.Mech.E., M.I.Mar.E.—Head of the Mechanical Section of the Plant Engineering Division, British Iron and Steel Research Association.

Comdr. Green received his engineering training at the Royal Naval Engineering College, Keyham, and the Royal Naval College, Greenwich. His last appointment in the Royal Navy was as Professor of Marine Engineering at Greenwich from 1947 to 1953.

L. E. Samuels, B.Met.E.—In charge of the Physical Metallurgy Group of the Defence Standards Laboratories, N.S.W. Branch, Sydney, Australia.

Mr. Samuels was educated at Melbourne University, graduating in Metallurgical Engineering in 1942. He then joined the Defence Standards Laboratories, where he has since been associated with the various physical metallurgy activities of the Laboratories, mainly at the N.S.W. Branch.

J. I. T. Green

A. Conway

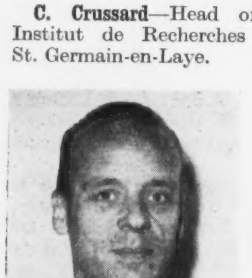
L. E. Samuels

J. Philibert

J. Philibert—On the staff of the Physics Department of the Institut de Recherches de la Sidérurgie (IRSID), St. Germain-en-Laye.

Monsieur Philibert received his technical education at the Sorbonne, where he studied mathematics, physics, and crystallography. He took up his present appointment with IRSID in 1953.

C. Crussard—Head of the Physics Department, Institut de Recherches de la Sidérurgie (IRSID), St. Germain-en-Laye.



C. Crussard

Professor Crussard was born in 1916, and graduated from the École Polytechnique. He then joined the School of Mines in Paris, and later founded the Centre de Recherches Métallurgiques at the School. He held the post of Director of the Centre de Recherches Métallurgiques until 1952, and in 1948 he became Professor of Physical Metallurgy at the School of Mines. He took up his present appointment in 1952.

The author of numerous papers on metal physics, Professor Crussard has visited the U.S.A. on a six-month mission, and also spent some time in India where he worked for the Indian Government on the planning of the new National Metallurgical Laboratory at Jamshedpur.

EDUCATION

Beilby Memorial Awards, 1954

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, have made awards from the Fund for 1954, of one hundred and fifty guineas each, to:

H. K. Hardy, M.Sc., Ph.D., A.R.S.M., in recognition of his work in physical metallurgy, with special reference to precipitation hardening and to the thermodynamics of phase equilibria in alloy systems.

J. W. Menter, M.A., Ph.D., A.Inst.P., in recognition of his work on surface phenomena, with special reference to the application of electron optical techniques to the elucidation of a wide range of problems.

Awards from the Fund are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering, and metallurgy, in which Sir George Beilby's special interests lay. In general, the awards are not applicable to more senior investigators but are granted as an encouragement to relatively young men who have done independent work of exceptional merit over a period of years.

University of Sheffield

Since Professor J. H. Andrew's retirement in 1950, Professor A. G. Quarrell has been Professor of Physical Metallurgy at the University of Sheffield, with responsibility for the Postgraduate School in that subject, and he has also been in charge of the Department of Metallurgy. In November, 1954, the University Council decided that the Department and the postgraduate school should be merged in a single Department and that Professor Quarrell should be head of that Department with the title of Professor of Metallurgy. At the same time it was decided to seek a new professor of Physical Metallurgy, and at a meeting of the Council on 18th March, 1955, it was decided to appoint R. W. K. Honeycombe, M.Sc., Ph.D., Senior Lecturer in Physical Metallurgy, to this Chair. Dr. Honeycombe took up his tenure of the Chair on 1st April, 1955.

Technical State Scholarships, 1955

Arrangements for the award of Technical State Scholarships to students from technical colleges, etc., have been made for 1955 and are on the same general lines as those for previous years.

Most of the scholarships will be offered to students who have obtained an Ordinary National Certificate or other equivalent qualification, and will enable them to pursue full-time Honours degree courses or equivalent courses at universities, university colleges, or other establishments for further education. A limited number of awards may also be made to enable candidates who, by part-time work, have obtained an initial qualification of university first degree or Higher National Certificate standard to attend approved post-graduate courses of study or research in applied science or technology.

The awards will be available for a minimum of one year and a maximum of three years. Candidates must give full particulars of the study or research that they intend to undertake, and must be recommended not only by the establishment at which they obtained their initial qualification but by that at which they propose to take a post-graduate course.

Full particulars of the Scholarships and application forms are being circulated to Principals of Establishments for Further Education, but additional copies may be obtained from the Ministry of Education (F.E.I (d)), Curzon Street, London, W.1.

NEWS OF SCIENCE AND INDUSTRY

Congress on Documentation of Applied Chemistry, London

The First International Congress on Documentation of Applied Chemistry will be held in London on **22nd–25th November, 1955.** In conjunction with the meetings, which will be held at the offices of l'Institut Français du Royaume Uni, Queensberry Place, London, S.W.7, there will be an exhibition of books and apparatus. Further particulars are available from the Honorary Secretary of the Congress, at 56 Victoria Street, London, S.W.1.

Electrical Power Convention, Brighton

The theme of the seventh British Electrical Power Convention, to be held in Brighton on **27th June–1st July, 1955,** will be "*Electricity and the Future.*" A session on electricity in relation to industry, to be held on 30th June, will include a paper on the use of electricity in the steel industry.

British Instrument Industries Exhibition, London

The third British Instrument Industries Exhibition will be held at Earls Court, London, from **28th June to 9th July, 1955.** The Exhibition, which is organized by F. W. Bridges and Sons, Ltd., will cover scientific and electrical instruments, industrial meters, automatic controls, scientific glassware, drawing-office equipment, etc. On the same dates the 10th International Printing Machinery and Allied Trades Exhibition is to be held at Olympia, and visitors will thus have the opportunity of visiting both Exhibitions.

Symposium in Madrid on Reactivity of Solids

An International Symposium on the Reactivity of Solids will be held in Madrid in the Spring of 1956. Further details and the exact dates of the Symposium will be given in a later issue of the *Journal*.

Vacuum Metallurgy

A new ½-lb. capacity resistance-heated furnace, suitable for sintering, melting, and casting in a high vacuum with a temperature limit in excess of 2000° C. has been produced by W. Edwards and Co. (London), Ltd. Provision is made for working in different atmospheres, and suitable controls and sight glasses are provided to allow full supervision of the melt. The furnace is detachable from a mobile pumping unit.

Another product of the Company is an experimental vacuum-arc furnace for the melting and coating of refractory metals and alloys at temperatures up to and above 4000° C. The furnace is suitable for use with both consumable and non-consumable electrodes, and employs water-cooled hearths or crucibles. A booster pump provides adequate capacity for the use of the vacuum-arc in research work.

Rust Prevention

A new metallic-zinc composition that can be applied like paint and is claimed to afford galvanic protection to iron and steel has been produced by Secomastic Ltd. The composition, known as ' Galvafroid,' is claimed to confer electrochemical protection under the most corrosive conditions and to prevent the spread of rust even if the coating is broken at any point. Specimen plates subjected to British Standards salt-spray and sulphur dioxide tests have indicated that the protection conferred by ' Galvafroid ' is comparable to that obtained by hot-dip galvanizing.

Further details are available from Secomastic Ltd. at 15 Upper Grosvenor Street, Park Lane, London, W.1.

Liquid Air Production

A new gas refrigerating machine that can be used to produce liquid air has been developed by Philips Electrical Ltd. and is known as the Liquid Air Installation PW7000. The plant is claimed to have distinct advantages over more orthodox compression refrigerators, which are not generally capable of producing temperatures below between — 60° C. and — 80° C., and temperatures of — 200° C. can be obtained quickly and easily.

Resins for Plastic Patterns

A new epoxy resin, known as ' Araldite ' Casting Resin M, has been developed for plastic pattern-making. It is claimed that shrinkage on setting is very low, and is negligible when fillers are used, and that the hardened resin is tough, durable, and dimensionally stable. It sets cold in 24 hr., or less if gentle heat is applied. The manufacturers are Aero Research Ltd., from whom further details are obtainable.

New High-Temperature Alloy

A new grade of Ni–Cr alloy for high-temperature furnace resistors has been produced by Henry Wiggin and Co., Ltd. Known as Brightray ' H,' it is a modified 80/20 Ni–Cr alloy and is intended for use as a heating element in electric resistance furnaces where the element operating temperature is in the range 1100–1250° C. The oxidation resistance of the alloy at temperatures above 1100° C. is stated to be better than that of the standard 80/20 alloy.

Changes of Address

The AMERICAN CERAMIC SOCIETY has removed to new premises at 4055 North High Street, Columbus, 14, Ohio.

The National Headquarters of the AMERICAN FOUNDRYMEN'S SOCIETY is now situated at Des Plaines, Illinois.

The BAIRD AND TATLOCK group of companies have opened new offices, showrooms, and warehouse at 58 Lever Street, Manchester, 1 (Tel. Central 0937-8).

The address of the CENTRE BELGO-LUXEMBOURGEOIS D'INFORMATION DE L'ACIER is now 3 rue de la Science, Brussels.

RILEY STOKER CO., LTD., have opened a new branch office at 43 Burton Road, Melton Mowbray, Leics. (Tel. Melton Mowbray 495).

THE STANTON IRONWORKS CO., LTD., have opened an enlarged office and warehouse at Wapping Wharf, Gas Ferry Road, Bristol (Tel. Bristol 24496).

The Glasgow office of BRITISH ELECTRO METALLURGICAL COMPANY, a division of Union Carbide Ltd., will in future be situated at 266 Clyde Street, Glasgow, C.1 (Tel. Central 6454). Mr. William Paton, the Company's field representative for Scotland and parts of Northern England, will be available at that address.

JENOLITE LTD. have removed to new premises at 13–17 Rathbone Street, London, W.1 (Tel. Museum 5411).

The London office of " *Precision Metal Molding* " has removed to new premises at 31 Palace Street, Westminster, London, S.W.1 (Tel. Victoria 2608).

MOXEY CONVEYOR AND TRANSPORTER CO., LTD., have removed to new premises at Glasgow, situated at 5 Wellington Street (Tel. Central 5535).

THE UNITED STEEL COMPANIES LTD. have opened a new District Sales Office at 55–56 Scottish Provident Buildings, Donegal Square West, Belfast (Tel. Belfast 29604). The Office will be under the Managership of Mr. J. A. I. Graham.

DIARY

3rd–4th May—L'ASSOCIATION DES INGÉNIEURS ÉLECTRICIENS OF THE INSTITUT ÉLECTROTECHNIQUE MONTEFIORE (A.I.M.)—International Conference on the Industrial Applications of Nuclear Energy—Liège, Belgium.

10th May—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Works visit to the Austin Motor Co., Ltd.

14th–22nd May—ACHEMA XI—Chemical Engineering Exhibition and Congress — Frankfurt - am - Main, Germany.

23rd–28th May—L'ASSOCIATION DES INDUSTRIELS DE BELGIQUE — International Conference on Non-Destructive Testing—Brussels.

TRANSLATION SERVICE

(The previous announcement was made in the April, 1955, issue of the *Journal*, p. 376).

TRANSLATION IN COURSE OF PREPARATION

(German). E. PFLAUME and F. BAUER: " Technical Investigation of the Operation of a Forge." (*Die Technik*, 1954, vol. 9, Mar., pp. 152–156.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

Mineral Resources of the British Commonwealth: Some Recent Developments. R. W. Willett. (*J. Roy. Soc. Arts*, 1954, **102**, July, 701–728). The mineral resources in the British Commonwealth are described under the headings: (1) Fertilizer group; (2) energy producing group; (3) metallic group; and (4) non-metallic group.—R. A. R.

The Development of Quebec-Labrador Iron-Ore Deposits by the Iron Ore Company of Canada. W. H. Durrell. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 283–289). The author discusses the part played by the Iron Ore Company of Canada in developing the Quebec-Labrador iron-ore deposits. He describes the location of the ore bodies and their magnitude, and considers the mining and transportation problems.—G. F.

ORES—MINING AND TREATMENT

Heavy Load Mine Hoist for Opencast Operations at Kiruna, Sweden. F. Landau. (*Min. J.*, 1954, **243**, Oct. 15, 425–426). The hoist described was designed to raise large tonnages (50 tons) at a slow speed (1·6 ft./sec.) over a relatively short distance (230 ft.). Automatic control is extensively used in order to reduce labour costs.—B. G. B.

Giant Excavator for Open Cast Mining Incorporates New Features. (*Min. J.*, 1954, **243**, Sept. 10, 293). A very brief account of a new excavator being constructed by the Marion Power Company, U.S.A., is given. The machine has a bucket capacity of 60 cubic yards and will be able to remove, at each bite, up to 100 tons of overburden.—B. G. B.

Ore Flow and Distribution at the New Preparation and Sinter Plant at Scunthorpe. D. M. Potter. (*Mech. Handling*, 1954, **41**, Oct., 590–596). Details are given of the new ore preparation and sinter plant installed at the Scunthorpe works of the Appleby-Frodingham Steel Co. Flow sheets are included of the passage of ore from the crushers, through the screens and sinter plant to the furnaces.—D. H.

Advantages Resulting from the Precrushing of Ore at the Face. M. A. Mercier. (*Rev. Ind. Min.*, 1954, **35**, Sept., 951–960). To overcome the disadvantages associated with the large lumps obtained by the mechanical mining of iron ore, primary crushing has been studied at the Droitaumont mine. The equipment is described and reported benefits include a greater output and easier loading of wagons.—A. G.

Agglomeration Tests on Sierra Menera Ore—Sintering and Pelletizing Tests. E. Charro Sanchez and J. A. Boned Sopena. (*Inst. Hierro Acero*, 1954, **7**, Apr.-June, 208–230; July-Sept., 357–366). [In Spanish]. The physical and chemical characteristics of the ore (75·5% Fe_2O_3, 3% Mn_3O_4, 6·4% SiO_2, 0·059% P, 0·172% S) were investigated before sintering; the testing methods and results are given. The experimental sinter machine is described and the results obtained from 27 sinters are discussed. Similar tests on pellets and better characteristics were obtained from pellets made of the finer raw materials.—P. S.

Permanent-Magnet Separators for the Dry Preparation of Strongly Magnetic Iron Ore Fines. E. Laurila. (*Stahl u. Eisen*, 1954, **74**, Dec. 2, 1659–1661). The theory and mode of operation of permanent-magnet separators are discussed. The principles of design of the separator and the behaviour of a magnetic powder in the field of a moving magnet are described. The only power required for the process is that for the motor. The magnetic drum is 400 mm. in dia. and 1–1·5 m. long. The results obtained compare favourably with those of conventional separators. The throughput of the separator is from 7 to 15 tons/hr. for a drum 1-m. long, according to the quality of ore and the required degree of purity.—T. G.

Steel Industry Insures its Future—with Taconite. (*Steel*, 1954, **135**, Sept. 13, 76–77). Plans for mining Mesabi Range taconite are mentioned, and the steps by which Preserve Mining Co. prepare concentrate for blast-furnace charging are given. The taconite is finely ground, magnetically concentrated, balled-up, and baked. One ton of pellets (62·5% Fe) is produced from 3 tons of ore.—D. L. C. P.

Reducing or Reducing and Oxidizing Roasting of Brown Iron Ores. W. I. Parfenow. (*Mining News*, (Russia), 1949, **7**: *Met. u. Giesserei Techn.*, 1954, **4**, Sept., 394–396). The following conclusions are drawn from laboratory and small-scale industrial tests: (1) Highest degree of uniformity in magnetic characteristics of ores was attained with sizes below 1 in.; (2) best results were obtained at a temperature of 650° C.; and (3) the reducing-cum-oxidizing roasting process is simpler and safer than reduction roasting and should therefore be preferred.—L. J. L.

Aspects of Swedish Iron Ore Concentration. P. G. Kihlstedt. (*Jernkontorets Ann.*, 1954, **138**, (9), 499–538). [In Swedish]. The choice of iron contents in the concentrates obtained from different ores was investigated to ensure optimum adaptation to the Swedish coke blast-furnace process. An evaluation formula for concentrates is presented based on the production costs of pig iron ; it enables comparisons between different types of ore and calculations of " cut-off " grades to be made. The importance of high concentration of apatite ores in pig and sponge iron production is mentioned. Flotation methods would increase iron recovery in the concentration of hematite ores.—G. G. K.

Agglomeration of Iron Ore Concentrates and Coke Dust Using Lime and Carbon Dioxide. L. A. Conradi and B. Sæther. (*Tidsskr. Kjemi, Bergvesen Met.*, 1954, **14**, Sept., 129–132). [In Norwegian]. Results are given of tests on the suitability of iron ore agglomeration by means of lime and CO_2, with special reference to the optimum heating time obtainable. Curves show tensile strengths of agglomerate as a function of storage and carbonizing time, and rough costs are calculated for a typical plant.—G. G. K.

Compacting Blast-Furnace Dust. S. Ebr and L. Houska. (*Hutník, (Prague)*, 1954, **4**, (9), 272–274). [In Czech]. Experiments designed to devise an economic method for compacting iron-rich blast-furnace dust, which is too fine for pelletizing, are described. A solid mass having a compressive strength of about 0·5 ton/sq. in. was obtained on treating the dust (60%) with lime (5%) and ground blast-furnace slag (35%). This was suitable for agglomeration, but further work is being carried out to increase the iron content of the product.

FUEL—PREPARATION, PROPERTIES, AND USES

Some Aspects of Coal Pyrolysis. C. Ellis. (*Inst. Gas Eng., Publ. No.* 436, Nov. 24–25, 1953). The author surveys the results of various investigations on the pyrolysis of coal and discusses the most important phenomena that occur as it is heated to 3000° C. The principal conclusion is that the course of events in each stage depends on the detailed treatment in the preceding stages.—L. E. W.

Overcoming the Obstacles to the Full Use of Fuel. M. W. Thring. (*J. Inst. Heating Ventilating Eng.*, 1954, **22**, Sept., 231–237). The author discusses the three obstacles which prevent the full use of fuel and considers their relative importance in different systems. The obstacles are: (1) The conductivity of the furnace walls; (2) factors affecting combustion efficiency; and (3) the thermal resistance between flame and charge. By applying the available experimental data (based particularly on the trials at Ijmuiden) and established theoretical principles, the author indicates how these problems may be overcome.—L. E. W.

Combustion and Radiation Characteristics of Oil and Coke-Oven Gas Jet Flames. M. W. Thring. (*Engineer*, 1954, **198**, Oct. 8, 499–501). The author shows how fuel consumption in melting steel in the O.H. furnace can be reduced by increasing the bath coverage by the flame or the flame emissivity; there is an optimum flame length for each stage of melting. Flame length for a given fuel input can be controlled by varying the jet momentum or using twin burners. Flame emissivity depends on the type of fuel, particularly the carbon/hydrogen ratio. Coke-oven gas gives a non-luminous flame, although there are possibilities of making it luminous by preheating the fuel.—M. D. J. B.

Interface Extension versus Upper Limiting Time/Mean-Energy/Release Rates of Constant-Pressure Steady-State Combustion Process. W. J. Wohlenberg. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 679–688).

Theory of Laminar Flame Stability. I. Analytic Stability Condition. II. General Numerical Method and Application to Typical System. J. B. Rosen. (*J. Chem. Phys.*, 1954, **22**, Apr., 733–748). The stability of propagation of a combustion wave is defined by solving a linearized system of partial differential equations in general terms and deducing stability limits. When solved for a particular choice of parameters, the steady-state equations provide information on other characteristics of the combustion wave.—J. O. L.

The Efficient Generation of Industrial Steam—Reducing Losses in Flue Gases. D. C. Gunn. (British Assoc.: *Engineering*, 1954, **178**, Sept. 10, 335–338). The author examines what improvements are possible in coal utilization in industrial boilers. Lancashire, Economic, Scotch marine, Cornish, and waste-heat boilers are discussed in detail and the causes of inefficiency considered. Experimental work carried out by the Brit. Coal Utilisation Res. Assoc. is described.—M. D. J. B.

Studies in Bomb Calorimetry. I—Determination of the Calorific Value of Solid Fuels. R. A. Mott and W. C. Thomas. (*Fuel*, 1954, **33**, Oct., 448–461). The ignition, physical state of the fuel, choice of crucible, and oxygen requirements for complete combustion of solid fuels in a bomb calorimeter are discussed.—B. G. B.

Studies in Bomb Calorimetry. II—Determination of the Calorific Value of Liquid Fuels. J. E. Barker and R. A. Mott. (*Fuel*, 1954, **33**, Oct., 462–479). The difficulties of accurately determining the calorific value of liquid fuels are discussed. Owing to the very rapid combustion of liquid fuels which occurs in bomb calorimetry, precautions must be taken to slow down the combustion of the lighter fuels to avoid dangerous pressures being developed in the bomb. The methods adopted are described.—B. G. B.

Chemical Engineering and Coal Preparation. A. T. Steadman. (*Chem. Process Eng.*, 1954, **35**, Sept., 267–271). The aspects of coal preparation of interest to the chemical engineer are broadly discussed. Chemical engineering problems arise principally in the washing and separation plants and to a lesser extent in materials handling, size reduction, screening, and water clarification.—L. E. W.

Note on the "Optimum Degree" of Coal Washing. J. K. Matthews. (*J. Inst. Fuel*, 1954, **27**, Sept., 430–437). The author demonstrates that since (*a*) cleaning coal, and (*b*) mineral matter in coal being used, cause loss of heat units, it is possible to calculate an optimum degree of cleaning. Required are: (1) Details of the coal; (2) its possible use, treated and untreated; (3) the location of use; and (4) costs. Three coals are considered in worked examples.—D. L. C. P.

The Goldschmidt Coke-Oven Door. G. Cellan-Jones. (*Coke Gas*, 1954, **16**, Aug., 307–310). The Goldschmidt door consists of a vertical passage 5 to 6 in. square in the refractory plug of the door, linked by openings to the oven at the top and the bottom. Gases evolved in the lower part of the oven have an easy passage to the free space above the charge or to the Goldschmidt flue if there is one. This prevents leakage and all its accompanying difficulties. Doors of this kind have been used for about a year in this country. Their design and operation, and improvements in production when they are used, are summarized and discussed. They overcome many of the known difficulties in the use of self-sealing doors with British coals.—T. E. D.

Coal Carbonization Plant at Fishburn, Co. Durham. (*Engineer*, 1954, **198**, Nov. 19, 695–698: *Gas World*, 1954, **140**, Nov. 20, 1258–1265: *Engineering*, 1954, **178**, Nov. 19, 661–664: *Iron Coal Trades Rev.*, 1954, **169**, Nov. 19, 1203–1214: *Times Rev. Indust.*, 1954, **8**, Dec., 34, 37: *Gas Times*, 1954, **81**, Nov. 12, 256–260, 262–270: *Coke and Gas*, 1954, **16**, Dec., 469–476, 481). The first of the new National Coal Board's coal carbonizing plants, at Fishburn, is described in detail. The plant which has a daily carbonizing capacity of 1000 tons of coal, comprises 50 coke ovens, extensive handling, blending, crushing, and by-product installations.—M. D. J. B.

Gas for Steelmaking and Other Purposes Obtained by the Gasification of Lignite with Oxygen and Steam. J. Jílek. (*Paliva*, 1954, **34**, (10), 267–276). [In Czech]. An analysis of the cost of pressure gasification of lignite by means of oxygen and steam shows that the method can yield heat at the same cost as the ordinary gasification of graded coal with moist air at ordinary pressures. Production of gas by gasifying coal dust with oxygen and steam in producers utilizing Koppers type burners is shown to be less advantageous.—P. F.

The Gasification of Coal. (*Organisation of European Economic Co-operation* TAR/99(52)1, Mar., 1953). This report of an OEEC mission is concerned primarily with the gasification of mined coal although underground gasification and oil-synthesis methods are also discussed. Six methods of gasification are considered; three are the subject of small and large scale experiments in Europe and the other three are being studied in the U.S.A. Details of each process are given. B. G. B.

Gas Main Flue Cleaning Plant: A Recent Installation at the Works of Steel, Peech and Tozer. M. Keith. (*Brit. Steelmaker*, 1954, **20**, Aug., 324–326). Brief details are given of the construction and method of operation of the Reiss flue-cleaning plant incorporated with a new overhead gas main at the works of Steel, Peech and Tozer. The operation of the blowing system and means of dust disposal are outlined.—G. F.

Oil Fuel in the Steel Industry. (*Coke Gas*, 1954, **16**, Sept., 339–340). In 1953, 782,000 tons of fuel oil were used in open-hearth furnaces, and 439,000 tons in other furnaces in the steel industry. Gross coke consumption used to produce a ton of steel-making pig iron has been reduced from 22½ cwt. in 1945 to 20½ cwt. in 1953. Unfortunately oil is expensive, even in areas near refineries. The extent to which fuel oil is likely to replace coal, coke and gas in the steel industry is discussed, and its most advantageous use is considered to be in open-hearth steel-making.—T. E. D.

TEMPERATURE MEASUREMENT AND CONTROL

Open Hearth Bath Temperature Measurement. J. H. Richards. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 96–98). The importance of a stringent maintenance programme to ensure reliability and accuracy in the measurement of O.H. bath temperatures is stressed, and details are given of the installations and maintenance of the immersion units and recording apparatus at the United States Steel Corp.—G. F.

Thermocouple Bath-Temperature Measurement. Bethlehem Steel. T. B. Winkler. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 98–102). Details are given of the equipment and practice used at the Lackawanna plant of the Bethlehem Steel Co. for measuring O.H. bath temperatures. The influence of temperature control on steel quality is outlined.—G. F.

Thermocouple Bath-Temperature Measurement. Steel Company of Canada. J. P. Orton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 103–107). The successful adoption of tapping-temperature control at the Hamilton Works of Steel Company of Canada Ltd. is described, and brief details are given of the installations. The degree of control exercised is outlined, and its effect on production and steel quality is considered.—G. F.

Manual Control of Firing Rates at the Open Hearth by Roof-Temperature Measurements. L. N. McDonald. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 192–193). Instruments for the continuous measurement of roof temperature are in service at the Edgar Thomson Works of the United States Steel Corp., and are used as an aid to the manual control of the firing rate. The practice is briefly described.—G. F.

Automatic Open Hearth Roof-Temperature Control. F. S. Swaney. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 193–197). The O.H. furnaces at the Pittsburgh works of Jones and Laughlin Steel Corp. are equipped with automatic roof temperature control, the primary element being a radiation pyrometer sighted on a refractory disc in a silicon carbide target block. Details of the system are given, and necessary maintenance is outlined.—G. F.

Automatic Roof-Temperature Control on Tilting Open-Hearth Furnaces. A. W. Thornton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 198–200). The author gives brief details of the automatic roof-temperature control system at the National Works of the United States Steel Corp., and indicates the improvement in roof life and production which has resulted since its installation.—G. F.

Front-Wall Rayotube Installation Used at Geneva Works. E. Richards. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 200–201). The O.H. furnaces at Geneva works of the United States Steel Corp. are fitted with Rayotube front-wall radiation pyrometers for recording the roof temperature and automatically controlling the liquid-fuel input. Brief details are given and the important factors involved in maintaining good operation are listed.—G. F.

Measurement of Bottom Shell Temperature in the Electric Furnace. D. G. Harris. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 91–94). Some of the electric furnaces at the Republic Steel Corp. have areas of the bottom shell enclosed in blisters with base-metal thermocouples installed in the enclosed air pockets, the temperatures of which are directly related to those of the particular area of the furnace bottom. Typical results are presented, and the use made of the readings is indicated.—G. F.

Measurement of Bottom Shell Temperatures. H. C. Bigge. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 95–100). Rare-metal thermocouples are inserted through the bottom shell into the furnace bottom lining in the electric melting shop of Bethlehem Steel Company. Details of the installation are given and typical records are presented. The value of the readings in indicating the condition of the bottom is shown.—G. F.

REFRACTORY MATERIALS

The Influence of Alumina Content on Refractory Products. L. Halm. (*Mitaux-Corrosion-Indust.*, 1954, **29**, Oct., 385–398). The Al_2O_3–SiO_2, CaO–SiO_2–Al_2O_3, Na_2O–SiO_2–Al_2O_3, K_2O–SiO_2–Al_2O_3 and FeO–SiO_2–Al_2O_3 phase diagrams are discussed in relation to the performance and use of refractory materials. The proportions of liquid and mullite in SiO_2–CaO–Al_2O_3 bricks at 1600° C. and their effects on the properties of the bricks are considered. The structure and properties of high alumina (60%) and silica bricks are reported. The influence of lime and alumina on the percentage liquid formed at 1600° and 1650° C. in silica bricks is discussed. There is an optimum lime content for a given alumina content for minimum liquid formation.—B. G. B.

Influence of the Properties of Silica Bricks on the Life of Large Open-Hearth Furnaces. F. Stebel. (*Hutnik*, (Prague), 1954, **4**, (6), 234–235). [In Czech]. A statistical analysis of works tests shows that uniformity of density of silica brick is conducive to long roof life, the number of heats in 200-ton open-hearth furnaces falling from over 100 to under 50 as the scatter in the density increased from about 3 to 7%. Results relating roof life to brick permeability, softening point, and compressive strength are given. Brick densities should be kept within the optimum limits of 2·40–2·45 g./c.c. as is required by Czechoslovak Standard Specifications.

Destruction of Refractory Bricks in a Carbon Monoxide Atmosphere. E. Högberg and S. Hedén. (*Jernkontorets Ann.*, 1954, **138**, (10), 655–664). [In Swedish]. Tests show that the main obstacle to refractory improvement is the catalysing effect of iron oxide particles during carbon precipitation. One method of reducing these iron spots is to fire the refractory at high temperatures, whereby the iron is transformed to a complex silicate glass or other less active compound. Another method is to soak the bricks in a 30% solution of aluminium sulphate or magnesium chloride. Good results were obtained when such bricks were tested in accordance with British Standards.—G. G. K.

A New Crystalline Silica. P. P. Keat. (*Science*, 1954, **120**, Aug. 27, 328–330). From a study of the role of soda in the crystallization of amorphous silica under hydrothermal conditions, the author has identified a new crystalline form of silica which possesses a characteristic structure and physical properties. This new phase has a small negative mean linear thermal expansion up to 550° C. and higher. (10 references).

The Behaviour of Silica Bricks in Open-Hearth Furnace Roofs. K. Konopicky. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1402–1413: *Iron Steel Inst., Translations Miscellaneous Series, No.* 227). Silica bricks from four German makers, each type in both the fully and partly transformed state, were compared in panel trials in four furnaces and examined at the end of each campaign. The conclusions were: Bricks fired to a specific gravity of 2·40–2·44 were in no case worse and often better than those fully fired (sp. gr. 2·34–2·37). There was no difficulty in use in any of the furnaces. This result in part contradicts experience in other countries. It was confirmed that alumina and alkalis are detrimental to the life. TiO_2 uniformly distributed in the raw materials, on the other hand, appears to decrease the wettability by iron oxides. For furnace parts subject to heavy wear it is important to restrict the amount of lime in the bricks. A porosity of over 25% shortens the life considerably. Bricks with permeabilities of over 100×10^{-3} c.g.s. had shorter lives than those of the same composition and porosity but with permeabilities of 30–60 $\times$ 10^{-3} c.g.s.—J. P.

Contribution to the Study of the New Refractory Brick "Almulit." G. Hecht and R. Gasquard. (*Silicates Indust.*, 1954, **19**, Aug.-Sept., 283–287). The mechanical, thermal, and crystallographic properties of a new type of silica brick for open-hearth furnaces are described. The material seems to be superior in certain respects at very high temperatures to the silica bricks now in use. The fusion point, measured with Seger cones, was about 1805° C.—P. F.

The Thermal Radiation of Refractory Materials at High Temperatures. M. Michaud. (*Silicates Indust.*, 1954, **19**, June-July, 243–250). The emissivity of a number of silica and alumina refractories in the range 1000–1600° C. was determined from measurements of the total radiation, obtained with a total-radiation pyrometer, and from the true black-body temperature. Total, but not monochromatic emission by silica is higher than that by alumina. Both types of emissivities decrease somewhat as the temperature is raised—total emissivity more rapidly than monochromatic. The emissivities were affected more by grain size than by chemical composition. Coarser grains lead to higher emissivity. Colouring of the refractories, *e.g.*, by iron oxide, increases the total and monochromatic emissivities; coarse grained coloured silica–alumina refractories have emissivities of the order of 0·7 to 0·8; for silica bricks the value is about 0·5 to 0·6.—P. F.

Some Observations on the Behaviour of Runner Refractories. G. van Gijn and K. Kooij. (*Silicates Indust.*, 1954, **19**, Oct., 317–325). Several silica bricks (55–67% SiO_2) were subject to corrosion and wear tests by inclusion in runners for molten steel together with other standard bricks, the latter serving as controls. The degree of attack by the steel, determined microscopically, depended primarily upon the refractory properties of the clay component, the degree of surface fusion during pouring being of secondary importance. Bricks containing more than 30% alumina were strongly attacked by the killed open-hearth steel which had a high manganese/silicon ratio.—P. F.

Rammed and Castable Refractories for Open-Hearth Service. R. R. Fayles. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 265–267). The author discusses the introduction of rammed and castable refractories in O.H. furnace practice, and describes some of the recent developments and applications. The advantages of these materials over normal brickwork are outlined.—G. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Oxygen-Low-Shaft Furnace and Its Operation. H. Erne. (*Stahl u. Eisen*, 1954, **74**, Dec. 2, 1644–1648). The oxygen-blown low-shaft furnace described is 3·75 m. high and 1·5 m. in inside dia. It has four water-cooled copper tuyeres 40 mm. in dia. The maximum blast used is 3100 cu. m./hr. (NTP); up to 250 cu. m./hr. (NTP) of pure oxygen can be added to the blast. The oxygen in the blast varied between 28 and 40%, and the blast pressure between 700 and 2000 mm. WG. Sinter containing 44% iron and lignite was charged during a week's trial run. The quality of the iron produced was satisfactory; the slag contained less than 2% iron, but the test showed that the process is not yet competitive. Attempts were made to produce foundry iron from steel scrap on an economic basis, and to remelt iron. The coke rates were 8–10% for remelting and 20–30% for producing foundry iron from steel scrap without adding pig and iron scrap, the rate depending on the amount of rust. An addition of only 10% pig reduced the coke consumption by 25–30%. The sulphur in all irons produced was less than 0·05%.—T. G.

Some Data on Russian Blast-Furnace Operation. (*Iron Coal Trades Rev.*, 1954, **169**, Oct. 29, 1035–1037). The available literature on Russian blast-furnace operation is surveyed with special reference to blowing rates, evaluation of performance, coke rate, and constant humidity blast.—G. F.

Lincolnshire Iron Industry: Developments in Blast-Furnace Burden Preparation. G. W. Wells. (*Iron, Coal Trades Rev.*, 1954, **169**, Oct. 29, 1045–1046). A brief history is given of the Lincolnshire iron industry, and attention is given to some of the more important developments, particularly in the preparation of the blast-furnace burden.—G. F.

Special Process of Bessemerizing the Bath in the Blast-Furnace. K. Kanamori and others. (*Tetsu to Hagane*, 1954, **40**, July, 665–675). [In Japanese]. Experiments are reported, using a 3-ton experimental blast-furnace, designed to assist with the use of local high-sulphur ores. A slanting tuyere was devised for blowing air or oxygen direct into the hearth, and one operation per cast enabled a good iron to be produced. The device also enabled metal and slag samples to be extracted at will, and lime and ferrosilicon to be blown into the bath. The process generally enables a close control of hearth conditions, and hence iron quality, to be maintained.—K. E. J.

A Survey of the Results of the Examination of the Brickwork of Blown Out Blast-Furnaces. (*Iron Steel Inst. Special Report No.* 51, 1954, Oct.). A comprehensive account of the results of the examination of 80 blast-furnaces from 30 works after blowing out is given. Details of the campaign of each furnace, the design of furnace, the type of brickwork used, and the reason for blowing out are presented in tabular form. The condition of the brickwork after the campaign is described. The data are discussed under two headings, stack failures and hearth breakouts. Details of 12 furnaces which have given particularly good service are tabulated. The effect of furnace design and operation on lining life is discussed.

Desulphurizing with Solid Lime. S. Eketorp. (*Blast Furn. Steel Plant*, 1954, **42**, Oct., 1159–1161, 1177). A short survey is made of the use of solid lime to desulphurize pig iron. Data relating to practical experience obtained in Sweden are given and the approximate cost of desulphurizing 200,000 tons of pig-iron/year from 0·1 to 0·01% sulphur is calculated.

Metal-Slag Interfacial Tension and the Mechanism of Desulphurization. P. Kozakevitch, G. Urbain, and M. Sage. (*Compt. Rend.*, 1954, **239**, July 15, 166–168). The interfacial tension between sulphur-bearing metal and a desulphurizing slag is very low. It increases rapidly as the sulphur moves into the slag. A sulphur-bearing melt is easily dispersed in slag with the formation of droplets whose coalescence is then promoted by the growth of interfacial tension. It is suggested that this mechanism is responsible for the speed of desulphurization in the blast-furnace. A brief description of the apparatus used in the experiments is given.—G. E. D.

On Activities of Coexisting Elements in Molten Iron. II. The Activity of Silicon in Molten Fe–Si System. K. Sanbongi and M. Ohtani. (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1953, **5A**, Aug., 350–357). [In English]. Data were obtained from an electrode concentration cell at 1520–1540° C., enabling the activity of silicon in molten iron and the free energy change in the reaction Si (liquid) = Si (in Fe) to be calculated. The activity conforms with Henry's law at low concentrations, but with Raoult's law at high concentrations, and its change with temperature is not marked.—K. E. J.

Correlating Blast-Furnace Operating Concepts. C. E. Agnew. (*Steel*, 1954, **134**, May 17, 106–117; June 21, 142–156; **135**, Aug. 2, 94–98). These are the first parts of a series of articles explaining the roles of practical experience and technical science in understanding and running the blast-furnace. Conceptions of the mechanisms of the blast-furnace process are considered critically in the light of modern science. The effects of operating variables (including blast humidity and oxygen content) are dealt with. The field for economical application of oxygen-enriched blast is considered to be in balancing the heat required for burden preparation in the stack with that for smelting in the hearth.—D. L. C. P.

The Viscosity of Blast-Furnace Slags. P. Kozakevitch. (*Rev. Mét.*, 1954, **51**, Aug., 569–587). Measurements by a viscometer with coaxial cylinders show that the crystallization of basic slags begins between about 1450° and 1540° C. The slags from acid charges are generally homogeneous liquids and an efficient fluxing agent must disrupt the lattice. Basic slags are often heterogeneous and fluxes which lower the liquidus point are best. The effects of barytes, sulphur, fluorspar, and magnesium fluoride on viscosity have been determined.—A. G.

Carbide Drilling Speeds Removal of Tough Slag Deposits. D. L. Tunsberg. (*Iron Age*, 1954, **174**, July 8, 98–99). The best method found to drill explosive holes into a 6 ft. thick scaffold inside a blast-furnace is described. This involved using three-wing tungsten carbide drag bits threaded on to a hollow shank in a hand-held rotary drill. An air blast through the shank and bit kept the bit cool and disposed of the drillings.—D. L. C. P.

TREATMENT AND USE OF SLAGS

Blast-Furnace Slag an Important Substance for Soil and Plants. F. Schlegel. (*Met. u. Giesserei Techn.*, 1954, **4**, June, 274–275). The use of blast-furnace slag as a fertilizer is advocated. The desirable properties of a slag for this purpose are pointed out and it is shown the blast-furnace slag is suitable.—R. A. R.

The Production of Basic Slag in Talbot Furnaces. J. Kaspar. (*Hutnik*, (Prague), 1954, **4**, (8), 236–238). [In Czech]. Factors to be considered in attempts to utilize phosphorus-rich slag efficiently for subsequent conversion into fertilizer are discussed.—P. F.

DIRECT PROCESSES

New Iron Industry in South Africa. W. Williams. (*Chem. Process Eng.*, 1954, **35**, Sept., 285). A new plant, which will produce pig iron from low grade ores by the Krupp-Renn process, has been erected by the Dominion Iron and Steel Corp. at Airlie, South Africa. This article deals briefly with the raw materials and their availability, and the kiln operation.—L. E. W.

PRODUCTION OF STEEL

Controlling the Flow of Materials by a Materials Balance for Each Heat. G. Strohmeier. (*Stahl u. Eisen*, 1954, **74**. Nov. 18, 1594–1602). A system for controlling the flow of materials in and out of departments of steelworks, involving

a combination of individual heat data sheets and punched cards, is described. The system covers all operations until the products of the heat leave the works. It is shown that the system enables prime costs to be checked, processing yields to be increased, processing time to be reduced, and comparisons between old and new plants to be made.—R. A. R.

Investigations on the Movement of Nitrogen during the Combustion of Carbon. K. G. Speith and H. Bücken. (*Stahl u. Eisen*, 1954, **74**, Dec. 2, 1648–1650). When blowing a converter with pure oxygen, the nitrogen is removed from the iron by purging action. The rate of removal is proportional to the rate of carbon elimination and is independent of the carbon content; the degree of removal depends, however, on the initial nitrogen content of the bath. Trials showed that as the carbon burns away the nitrogen is always taken from the iron no matter what refining process is used. More nitrogen is, however, often picked up by the bath than is removed by the CO owing to the large quantities of nitrogen introduced by the blast, especially in the basic-Bessemer process.—T. G.

The Effect of Limestone Additions on the Nitrogen Pick-Up in the Blowing of Steel. K. G. Speith and H. Bücken. (*Stahl u. Eisen*, 1954, **74**, Dec. 2, 1650–1652). Addition of limestone during the carbon elimination lowers the bath temperature and therefore the tendency to pick up nitrogen. Purging by the CO_2 released also retards the nitrogen pick-up. The CO/CO_2 ratio in the waste gases is not altered by the limestone, but the absolute contents of both gases are higher. It is assumed that the CO_2 from the limestone reacts directly with the iron. Calculations showed that an addition of 1 ton of limestone has the same effect as 450 cu. m. (N.T.P.) of blast. Limestone additions increase the rate of carbon elimination and at the same time reduce the quantity of nitrogen blown through the bath since less blast is needed.—T. G.

Metallurgy and Practice of the Basic Converter Processes. A. Weyel and H. Kosmider. (*Blast Furn. Steel Plant*, 1954, **42**, Sept., 1039–1047, 1065; Oct., 1162–1168). The chemical changes when blowing steel in the Bessemer converter are briefly considered and graphs and tables comparing the properties and composition of Bessemer and other steels are reproduced. European practice for manufacturing low nitrogen steels in the converter is discussed. Costs of various converter practices are reviewed. (35 references).—B. G. B.

Control of the Basic-Bessemer Converter by the Flame Brightness. J. Daubersy. (*Rev. Univ. Min.*, 1954, Series 9, **10**, Oct., 642–654). The application of photoelectric cells for the measurement of the brightness of converter flames is first considered. The brightness of actual converter flames in the red and green portions of the spectrum has been measured for blowing with air and with an oxygen/water-vapour mixture. It is possible to follow the changes occurring during the blow by measurement of the flame intensity in the green and red regions.—B. G. B.

Open-Hearth Furnace Fuels; Use of Various Fuels in Steelmaking. W. B. Wright. (West of Scotland Iron Steel Inst.: *Iron Coal Trades Rev.*, 1954, **169**, Sept. 24, 747–750). The author discusses the desirable flame characteristics in O.H. steelmaking and their effect on heat transfer and steel production. The fuels considered are producer gas, heavy fuel oil, creosote pitch or tar, and mixtures of coke-oven gas with blast-furnace gas, producer gas, and oil. Details are also given of results obtained with a burner of B.I.S.R.A. design.—G. F.

The Use of Gaseous Oxygen in Open Hearth and Converter Steelmaking. D. J. O. Brandt. (North East Metallurgical Soc.: *Brit. Steelmaker*, 1954, **20**, Nov., 428–434). The author discusses the successful application of gaseous oxygen in the iron and steel industry, with special reference to O.H. furnace and converter steelmaking. The processes described include oxygen enrichment and lancing in the O.H. furnace, desiliconizing blast furnace metal in the ladle, and, in converter operation, enrichment of the blast, mixed blast operation, and the downward oxygen blowing (L.D) process. A new development is the small-scale intermittent process to convert iron in the ladle directly into steel by oxygen lancing.—G. F.

The Development of Oil-Fired Open-Hearth Furnaces in Austria. F. Hönig-Hönigsberg. (*Stahl u. Eisen*, 1954, **74**, Nov. 18, 1583–1591). A detailed account is given of the design of oil-fired open-hearth furnaces, oil burners, and various types of oil firing, and flame propagation, bath temperatures obtained, and life of the furnaces are discussed. Oil- and gas-fired furnaces in Europe and U.S.A. are compared. European oil-fired furnaces have an output 15% higher than gas-fired furnaces. Further improvement is expected from furnaces specially designed for oil-firing, whereas most of the oil-fired furnaces now in use are converted gas-fired furnaces.—T. G.

Contribution to the Study of Decarburization in the Open-Hearth Furnace. P. Vallet. (*Rev. Mét.*, 1954, **51**, Oct., 709–722). The excess oxygen (ΔO), as defined by Larsen, may be explained in terms of the surface tension of the metal and the radius of the bubbles tending to form. A theory is evolved which suggests that the rate of decarburization is proportional to the carbon content and to ΔO. An approximate value for the activation energy of decarburization is deduced.—A. G.

Oxidation and Its Relationship to Steel Making. C. F. Christopher. (*Blast Furn. Steel Plant*, 1954, **42**, Sept., 1059–1065; Oct., 1178–1183). The chemical reactions occurring during steelmaking are considered in detail. The use of deoxidizers to minimize the porosity in ingots is discussed and data on the formation of iron sulphide inclusions are examined. Deoxidation practice using silicon and aluminium and the influence of the carbon content of the steel on deoxidation are reviewed.—B. G. B.

The Behaviour of the Chromium and the Manganese in the Basic Open-Hearth Furnace Taking into Account the Slag Composition and the Temperature. E. Maurer and K.-F. Lüdemann. (*Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin: Mitteilungen aus dem Eisen-Forschungsinstitut in Hennigsdorf*, 1954). A number of steel and slag samples were taken from several basic open-hearth chromium-alloyed heats, with a simultaneous determination of bath temperatures, in order to investigate the behaviour of chromium and manganese in the heats, in particular their distribution between slag and steel. The reaction $2[Cr] + 3(FeO) \rightleftarrows (Cr_2O_3) + 3[Fe]$ was described by the coefficient $K^b_{Cr} = [Cr](Fe)^{1.5}/(Cr)^{0.5}$. It was found that the relationship between the equilibrium constant $(K_{Mn})_{MB}$ and the CaO and SiO_2 content of the slag was valid for both alloy and carbon steels. The coefficient $(K^b_{Cr})_{ML}$ was determined in the range 1580–1750° C.; the influence of temperature in the chromium reaction is much greater than in the manganese reaction. The relationship between the chromium in the charge and the chromium yield was confirmed; this was not the case with manganese, at least in the range 0·8 to 1·5%. The possibility of obtaining a good chromium yield with a suitable degree of dephosphorization was studied; with a charge containing up to 1% Cr and a slag quantity of 10%, a chromium yield of 90% and simultaneous dephosphorization of 40% were possible.—L. D. H.

Quality Control in the Production of High-Sulphur Open Hearth Steels. J. H. Flaherty, jun. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 13–19). By eliminating silicon from the bath deoxidants, the Jones and Laughlin Steel Corp. has achieved substantial reductions in rejections on low-carbon, high-sulphur O.H. steels. The practice results in more desirable forms of inclusion and fewer heats off specification in carbon and manganese. Details of the practice are given.—G. F.

Training Personnel. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 20–40). The following papers were presented at this session of the conference:

How a Critical Shortage of Fuel Engineers for Open Hearth Operations Was Solved. W. Whigham, jun. (21–28).

Training of Open Hearth Personnel, Republic Steel Corporation, Cleveland. R. P. Carpenter. (28–29).

Training Open Hearth Personnel at Fairless Works. H. A. Parker. (30–32).

Training Open Hearth Personnel at Ohio Works. E. L. Wentz. (33–34).

Training Personnel at No. 2 and No. 4 Open Hearths, Bethlehem Steel Company. M. K. Morris. (35–37).

Training Open Hearth Personnel at Lukens Steel Company. C. H. Alexander. (38–40).

Sand for Acid Open Hearths. D. C. Williams. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 42–45). The author discusses the quality of sand suitable for acid O.H. practice.—G. F.

Bottom Repair in Acid Open Hearth Furnaces. J. B. Kopec. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 46–51). An analysis is presented of data from 14 firms relating to the time required for bottom repairs in acid O.H.

furnaces. The excessive amount of sand used and time required are attributed directly to the hearth area of the furnace and the sand 'setting' time after repair.—G. F.

Comments on Quality Problems—Open Hearth *vs.* Electric Furnace. A. H. Osborne. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 67–68). A brief comparison is made between the qualities of O.H. and electric furnace low-carbon rimming steels produced by the Armco Steel Corp., particular attention being given to hardness, tensile properties, and nitrogen contents.—G. F.

Quality of Alloy Steels—Open Hearth *vs.* Electric Furnace. B. R. Queneau. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 69–70). The author briefly compares the qualities of low-carbon and medium-carbon alloy steels produced in the O.H. and electric furnaces. The data indicate that with proper precautions, the O.H. furnace can produce low-alloy steels with properties approaching those of electric steels.—G. F.

Quality of Similar Grades of Carbon and Alloy Steels, Open Hearth *vs.* Electric Furnace. W. Huhn. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 71–72). The author discusses the quality of similar grades of steel made by the O.H. and electric processes at Crucible Steel Co. of America, and compares the deoxidation and pit practices of the two processes.—G. F.

Production and Quality of AISI C-1200 Series Screw Steels. S. Feigenbaum. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 75–76). High-sulphur free-cutting steels, until recently produced mainly by the acid-Bessemer process, are now made in the O.H. furnace at Jones and Laughlin Steel Corp. The practice is outlined, and some problems which had to be solved are briefly considered.—G. F.

Production and Quality of AISI C-1200 Series Screw Steels. I. A. Sirel. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 77–78). The author outlines the furnace practice at Youngstown Sheet and Tube Co. for the production of high-sulphur free-cutting steels in the O.H. furnace. Surface quality and machinability of the product compare favourably with those of the same grade of steel made by the acid-Bessemer process.—G. F.

Rimmed *vs.* Capped Steel. R. D. Hindson. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 80–85). The Steel Company of Canada Ltd. has replaced rimming steel by capped steel production to a large extent. The author indicates the superiority in yield of capped steel, and discusses applications for which it could successfully replace rimmed steel. The limitations of capped steel are also outlined.—G. F.

Rimmed and Capped Steels. A. N. Swanson. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 85–87). The author compares the characteristics and structures of rimmed steel and steel which is capped either mechanically or chemically. Capped steel gives the higher yield and greater uniformity of product, but requires more careful control.—G. F.

Factors Affecting Surface Quality of Aluminium-Killed Deep-Drawing Steel Sheets. R. J. Walter. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 88–90). The author briefly outlines the practice at the Wheeling Steel Corp. for the production of aluminium-killed deep-drawing steel sheets, and considers the factors affecting surface quality. Close control of both steelmaking and processing practices is necessary.—G. F.

Factors Affecting Surface Quality of Aluminium-Killed Deep-Drawing Sheets. W. R. Huber and E. L. Robinson. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 90–95). In discussing surface quality of aluminium-killed deep-drawing steel sheets, the authors consider the three main defects occurring in the slab stage, namely cracks, scabs, and sub-surface deoxidation products. Factors affecting their occurrence, and their relations to defects in the finished sheet, are discussed.—G. F.

Effect of Restricted Uptake Design on Refractory Consumption and Production Rate. E. B. Speer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 111–115). At the Gary works of United States Steel Corp., six furnaces have been rebuilt with longer hearths and decreased uptake area, and the author gives details of the changes in design. Data indicate that substantially increased production rates can be obtained from this single-uptake design, with little or no variation in fuel and with no greater refractory consumption.

Effect of Restricted Uptake Design on Production Rate and Refractories Consumption. M. J. Smith. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 116–119). A conventional double-uptake furnace at the Dearborn works of the Ford Motor Co. has been converted to single-uptake design with no other major changes. The author gives details of the conversion and indicates that, whilst effecting a saving in brickwork, it caused an increase in the fuel rate and a decrease in production rate.—G. F.

Economics of Port-End Construction. E. B. Speer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 121–122). The author outlines factors influencing the design of an efficient and economical port-end in an O.H. furnace, referring particularly to the problems encountered in large works.—G. F.

Economics of Port-End Construction. A. J. Voss. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 122–123). A brief comparison is made of the economics of port-end constructions in all-silica furnaces, all-basic furnaces, and silica-brick furnaces with end panels, tops of burner walls, and bridge walls of basic brick. At the Inland Steel Co. the all-basic single-uptake design has the highest productivity.

Economics of Open Hearth Port-End Construction. A. H. Sommer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 124–127). The author discusses the cost of maintenance on open-hearth port-ends, with particular reference to the design and to the use of silica, basic, or super-duty clay refractories. The data given refer to a small plant where cold metal is charged.—G. F.

Economics of Open Hearth Furnace Port-End Construction, Large Plants versus Small Plants. W. J. Scharfenaker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 127–128). The author points out fundamental differences between large and small plants which need to be taken into account in evaluating the economics of different types of port-end construction in O.H. furnaces.—G. F.

Hinged Slag-Pocket Doors. M. H. Weir. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 130–134). To facilitate slag removal from the slag pockets at the end of an O.H. furnace campaign, basic-brick doors have been fitted on the slag pockets at the Houston Works of the Sheffield Steel Corp. The doors weigh 18 tons and are hinged along the top edge. The time saving effected since their installation is indicated.—G. F.

Use of Special Explosives for Slag Removal. W. E. Brandt. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 140–142). At the Homestead works of the United States Steel Corp., Nitramon-S explosive is used to break up the slag in the O.H. slag pockets, the broken slag then being removed with back-hoes and tractors. Special shot holes are built into the pocket before the furnace campaign, and complete removal of the slag is possible in 8–16 hr. after the fuel has been taken off the furnace.—G. F.

Steam Jet System for Removal of Flue Dust. J. L. Peterson. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 143–146). At the Midland works of Crucible Steel Company of America, a steam jet system has been installed to remove dust from the regenerator flues. It has proved successful in preventing clogging and loss of efficiency towards the end of a campaign and in saving time during rebuilds. Details of the installation are given.—G. F.

Monolithic Refractories in Furnace Spouts. V. W. Jones. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 147–150). Furnace launders at the Middleton works of Armco Steel Corp. are made up with monolithic lining of rammed basic material. This method has considerably reduced costs, with easier and faster cleaning. The practice is briefly described and illustrated.—G. F.

Monolithic Refractories in Furnace Spouts at Bethlehem Steel Company. J. C. MacNeill. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 154–155). The practice of making up furnace launders with a rammed monolithic lining at Bethlehem Steel Company is outlined. They have advantages over the conventional brick linings in easier lining and skull removal, quicker drying, and less crane handling.—G. F.

Checker Problems. R. S. Bowers. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 156–157). The author briefly discusses some of the factors affecting the efficiency of O.H. regenerators, paying particular attention to design, quality of brick used, and cleaning.—G. F.

Checker Problems at Inland Steel Company. G. C. Lawton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 159–160). The author describes the checker installations in the three O.H. melting shops at Inland Steel Company, and considers some of the problems connected with them. Statistics of checker performance are given.—G. F.

Auxiliary Stack Checkers. C. N. Straney. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 161). Two 550-ton O.H. furnaces at Weirton Steel Company are fitted with auxiliary sets of secondary checkers in the furnace stacks, replacing in effect the conventional waste-heat boiler. These stack checkers preheat the incoming air to 430° C. before it reaches the primary checkers, contributing to a fuel consumption on these furnaces of about 6 gall./ton lower than on other furnaces. The installation is described and illustrated.—G. F.

Continuous Oxygen Analysis for Combustion Control in the Open Hearth. F. P. Hubbell. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 169–173). The author discusses the importance of combustion control in O.H. furnace operation, and considers the advantages in this respect of continuous oxygen analysis of the waste gas. The installation at the Munhall works of United States Steel Corp. is described, and typical results are presented.—G. F.

Atomization of Liquid Fuels As Related to the Overall Operation of Open-Hearth Furnaces. G. C. Primm. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 177–179). The author describes the experiences at South Works, Chicago, of United States Steel Corp. in the atomization of liquid fuel. He suggests that burner design is not the critical factor, and that efficiency depends largely on fuel and steam pressures. The possibilities of other atomizing agents, such as gas or air, are considered.—G. F.

Significance, Factors Involved, and Maintenance of Air Preheat. J. H. Kelley and G. E. Wenzel. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 181–184). The authors outline the importance of air preheat in O.H. operation, and discuss the three main factors, namely the quantity of primary air, the extent of air infiltration, and the checker temperature which govern the air temperature. The routine adopted at Sparrows Point plant of Bethlehem Steel Company to maintain air preheat is described.—G. F.

Manual Control of Firing Methods. H. W. Potter. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 186–187). Flame direction, fuel flow, and air-oil-steam ratios are all controlled manually at the Lukens Steel Co. Brief details of the practice are given.—G. F.

Scheduling Combustion Practice. J. R. Deppich. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 188–192). The author discusses some fundamental problems involved in controlling the firing of O.H. furnaces to a schedule, and outlines the practice at Sparrows Point plant of Bethlehem Steel Co. The advantages gained by this control are listed.

Heating-Up Open Hearth Furnaces after Rebuilds. C. N. Jewart. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 202–208). The author indicates that, in the heating of a silica brick, the critical temperature range is up to 315° C., and suggests that the heating up of furnaces after rebuilds should be planned accordingly. As an example, the practice employed at the Lackawanna plant of the Bethlehem Steel Company is described, where furnaces have been heated to tapping temperature in less than 16 hr. after rebuilding.—G. F.

Open Hearth Furnace Design at Fairless Works. H. A. Parker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 209–215). The author discusses interesting features of the fixed basic O.H. furnaces at the Fairless works of the United States Steel Corp., especially the design of the furnace, the regenerator system, the combustion system and waste-heat boilers, controls and instruments, and oxygen-jet devices.—G. F.

Recent Trends in Furnace Design in New Plants. A. K. Moore. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 215–217). The author outlines the layout of the new melting shop at the Hamilton works of the Steel Company of Canada Ltd., and discusses the main features of the furnace design and auxiliary equipment.—G. F.

New Bottcms and Refractories Used in Bottom Repair. J. F. Pollack. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 220–221). The method of preparing the furnace bottoms in the new Pittsburgh O.H. shop of the Jones and Laughlin Steel Corp. is described, and the importance of efficient fettling after each heat is stressed.—G. F.

New Bottoms and Refractories Used in Bottom Repairs. A. M. Kroner. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 221–223). The author describes the installation of O.H. furnace bottoms at the Inland Steel Co., East Chicago, and discusses their performance. Readings obtained during the heating-up period on thermocouples inserted at different depths in a new hearth are given.—G. F.

Significance Study of Open Hearth Variables. W. R. Weaver. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 224–225). The author discusses the value of the multiple correlation technique in assessing the significance of O.H. furnace variables. He illustrates its use by summarizing the results of a study of the effect of 22 variables on furnace production rate, the data being recorded during a complete campaign.—G. F.

Effect of Sample Size on Validity of Conclusions in a Study of Graphite versus Coal for Ladle Recarburization. W. A. Olsen. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 226–228). The author stresses the danger of using small numbers of results in studies of the relationships between different variables. He illustrates this by comparing the results of small-scale and large-scale trials comparing Mexican graphite and coal as recarburizing additions.—G. F.

Significance Studies at Wisconsin Steel Works. J. R. Brady. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 228–229). The author discusses the value of linear, partial, and multiple correlation techniques in the evaluation of operational variables. He gives examples of their use at Wisconsin Steel Works and summarizes the results obtained.

Productivity by the Use of Oxygen As Complicated by Sulphur Limitations. J. E. Hood. (*Amer. Inst. Min. Met. Eng., Proc. Nat. U.N. Comm.*, 1953, **36**, 230–232). A summary is given of the results of oxygen-lancing trials to increase the rate of decarburization at the Steel Company of Canada Ltd. For the use of the lance to be economical, lancing should be continued to a low carbon level, and furnace time after lancing should be reduced to a minimum. In regard to time the practice becomes uneconomical if any appreciable working for sulphur specification is necessary after lancing.—G. F.

Productivity by Use of Oxygen Lance As Complicated by Sulphur Limitations. L. R. Berner. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 233). The oxygen-lancing practice employed by the Inland Steel Co. is described and its advantages are indicated. Whilst lancing has no appreciable effect on rate of sulphur removal, it helps in the production of low-sulphur steels by rapidly building up a large volume of slag.—G. F.

Jet-Tappers. R. W. Smith. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 234–235). The ' jet-tapper ' device is now in routine use in four O.H. shops at the Gary works of the United States Steel Corp., and its advantages over normal tapping methods are outlined. The device gives a faster, more uniform stream and increases taphole life.—G. F.

Hydraulically Operated Ladle Stoppers. T. J. Hoby. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 236–244). The author describes the " Autopour " hydraulically-operated ladle stopper designed by the Republic Steel Corp., outlining the principles of operation and its component parts. Results obtained in routine use are given, and its advantages over the normal lever control are discussed. Problems encountered during the changeover are mentioned.

Comparison of the Electric and Open-Hearth Furnaces on an Economic Basis. T. R. Scott. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 245–247). The author summarizes experiences at the Houston plant of Sheffield Steel Co., with a new electric furnace, stressing primarily a comparison of cost-per-ton figures between this unit and the O.H. furnaces producing the same grades of steel over the same period. Given special preference in raw materials, the electric furnace can compete satisfactorily with the O.H. furnace on a cost basis when making ordinary-grade steels.

Economics of Electric Furnace *v.* Open Hearth with All Cold Metal Charge. J. E. Wilbanks. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 248–249). The author gives comparative costs for the same grades of steel made in the electric and O.H. furnaces working cold-metal charges at the Atlantic Steel Co. Experience indicates that costs are in favour of the electric furnace.—G. F.

Comparative Economics of Open Hearth and Electric Furnace Operation. C. L. King. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 250–251). The author discusses the relative economics of electric and O.H. furnace operation at the Kansas City plant of the Sheffield Steel Co., and draws attention to factors essential for an accurate comparison. He concludes that, dependent on plant facilities, electric furnaces will probably compete economically with the O.H. process.—G. F.

Effect of Reduced Aluminium Deoxidation on Cast Steel. A. W. Fastabend. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 253–260). The author compares the results obtained in the production of basic O.H. steel castings with two different ladle deoxidation practices, one using 2½ lb./ton of aluminium, and the other ½ lb./ton aluminium plus 3 lb./ton ferrotitanium. The second practice results in greater resistance to hot-tearing, thus producing a better quality of casting at lower cost. The effects of the two practices on the inclusion type are considered.—G. F.

Factors in Producing Quality Steel. C. F. Henzelman. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 262–264). The author emphasizes the necessity for good casting pit practice in the production of high quality steels, and discusses runner linings, taphole maintenance, lining and drying of ladles, and nozzle setting.—G. F.

Recarburising Heats with Coal or Coke Injected by Compressed Air. R. C. Buehl, R. J. Leary, and E. J. Ostrowski. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1953, **36**, 269–275). Tests were made on the 3-ton experimental O.H. furnace at the U.S. Bureau of Mines on the pneumatic injection of coke or coal to recarburize the bath. The equipment used is described and the results of the tests are discussed. The method is effective, rapid, and convenient, increasing the carbon content of the bath by 0·5% in 1 min. with a carbon recovery of 56%.—G. F.

Mill Gives Dornin Process First Big Test. G. A. Dornin, jun., R. H. Spence, and W. H. Meyer. (*Iron Age*, 1954, **173**, June 17, 141–144). The Green River Steel Corp., Kentucky, is now commercially producing quality steel by the Dornin process. Steel is melted by fully-killed steel practice and poured into special, squat, big-end up moulds, with a very heavy taper. After 1½ hr. the ingots are stripped, soaked, and submitted to a punching and upsetting procedure which isolates the small reject portion; the ingot is then forged before the bloom is scarfed, soaked, and rolled as usual. Thus sound ingots are produced, without the use of hot tops, and with minimum cropping loss; the steel is sounder, cleaner, and denser than that made by conventional practice.

Contribution to the Problem of Utilizing Scrap in the Production of Stainless and Heat-Resisting Steels. S. Kuběna. (*Hutník*, (Prague), 1954, **4**, (10), 298–299). [In Czech]. By using two furnaces, one containing the scrap, the other steel of very low carbon content, and mixing the products in a mixer, high quality steels of the stainless and heat-resisting types can be made using 35% scrap. This and other possible methods of scrap utilization are discussed.—P. F.

Incinerator Scrap and No. 2 Bundles Related to Adverse Heat Time. G. G. Mueller. (Amer. Inst. Min. Met. Eng. O.H. Conf., 1954 : *J. Met.*, 1954, **6**, Sept., Section 1, 952–953). Results obtained at the Duquesne works of United States Steel Corp. with different types of scrap in the O.H. furnace show that heat time, delay time, yield, and ability to make orders as scheduled are all adversely affected by the use of incinerator or standard No. 2 bundled scrap, to a degree determined by the amount charged.—G. F.

Ingot Yield Rises as Market Permits Greater Care in Scrap Selection. A. K. Moore. (Amer. Inst. Min. Met. Eng. O.H. Conf., 1954: *J. Met.*, 1954, **6**, Sept., Section 1, 953). The improved scrap position, and the consequent greater care in scrap selection for the O.H. furnaces at Steel Company of Canada Ltd. has resulted in a 2% increase in ingot yield and decreases in the final sulphur, slag volume, lime charged, and residual copper and tin.—G. F.

The Decline in the Thickness of Open-Hearth Furnace Roofs During a Campaign, and Methods of Determining It. M. Wald and J. Fries. (*Hutnické Listy*, 1954, **9**, (10), 594–601). [In Czech]. Experiments on the determination of the thickness of silica and magnesite roofs, carried out with instruments of new design, are described. In one method several thermocouples were used to measure the external roof temperatures in a given region, while the roof thickness was continuously measured by using the previously established relation between roof thickness and outer roof temperature. In the second method the thickness was ascertained by wire hooks inserted through slits in the roof.—P. F.

A New Method of Tapping Open-Hearth Furnaces by Means of the Explosion-Lance "OP 92." F. Jansch and F. Blažek. (*Hutnické Listy*, 1954, **9**, (9), 523–528). [In Czech]. Results of two years tests in various Czechoslovak steelworks with a gun of Czechoslovak design for tapping open-hearth furnaces are given, and desirable improvements are listed.—P. F.

Methane for Open-Hearth Fuel. D. W. Gillings. (*Metal Progress*, 1954, **66**, Aug., 91–93). A short account of the use of methane in Belgium for open-hearth furnaces, reheating furnaces, and coke-ovens is given.—B. G. B.

The Duplex Steel Making Process. W. E. Ward. (*Iron and Steel Engineers Group, 26th Meeting*, Newcastle-on-Tyne, Sept. 13–16, 1954, pp. 3–4). [*See J. Iron Steel Inst.*, 1955, **179**, Feb., 173].

Cleaning of Open-Hearth Checkers and Sewers During Operation. R. M. Jordan. (*Iron Steel Eng.*, 1954, **31**, July, 98–101). The author describes the practice adopted at the Lackawanna plant of Bethlehem Steel Co. for cleaning checkers. It is claimed that the use of water and air to blow the checker openings and the installation of agitators to blow the flues under the hot and cold-pass checkers coupled with close supervision have solved the problem of dirty checkers.

Improved Cleaning Techniques for Open-Hearth Checkers. J. J. Enochs and R. Kincaid. (*Iron Steel Eng.*, 1954, **31**, Aug., 79–82). The authors describe a new process for chemically cleaning open-hearth checkers, during operation of the furnace. This consists in playing a high pressure jet of chemical solvent against the hot deposits, causing these to disintegrate and to be removed by the flow of gases passing through the chamber. It is claimed that the process reduces fuel and maintenance costs and increases steel production. Nearly 100 chemical cleaning treatments of this type are in operation in the U.S.A.—M. D. J. B.

Behaviour of Oxygen during Oxidizing Period in the Acid Open-Hearth Furnace Process. Y. Nakagawa. (*Tetsu to Hagane*, 1954, **40**, June, 585–592). [In Japanese]. The study concentrated on the oxygen supplied from additional ore, the atmosphere and FeO in the slag, and on the calculation of slag weight and the additional limestone needed. The oxygen from the ore was influenced by slag basicity, that from atmosphere by the physical conditions of the slag, and that from the FeO by the chemical slag conditions, amount of limestone, and temperature. The distribution of oxygen used in oxidizing carbon, silicon, and manganese was assessed.

The Electric Ingot Process. (*Iron Steel Eng.*, 1954, **31**, Aug., 154–157). **Electric Ingot Steel—Old Process Solves Jet Age Problem.** (*Steel*, 1954, **135**, Aug. 9, 106–108). **Electic Ingot Process Makes Steel in Ingot Mould.** (*Iron Age*, 1954, **174**, Aug. 5, 127–130). A brief description is given of a method for continuous melting and casting, owned by the M. W. Kellogg Company. The method consists of passing strip through a tube-forming machine where it is formed into a cylindrical electrode with edges butted. The electrode feeds into a water-cooled mould; when the level of metal in the mould rises, the mould is retracted from the machine and this continues until the desired length of ingot has been made.

Production of Chromium–Nickel Steel in an Acid Electric Furnace. M. M. Rutman. (*Liteĭnoe Proizvodstvo*, 1954, (4), 28). [In Russian]. A brief description is given of charging methods which are said to facilitate control of the silicon when producing chromium–nickel steel in an acid electric furnace.

The Production of Hot Rolled Transformer Sheets with Low Watt Losses. M. Markuszewicz, J. Groyecki, and A. Zawada. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6**, (3), 105–119). [In Polish]. The authors tried to decrease the watt losses in sheets by an additional anneal, by a change in annealing conditions, and by a selection of sheets according to their position in packets. These trials, however, brought only a small improvement. Experimental melts in an 8-ton electric furnace were then prepared under various operating conditions. Intensive boiling during initial oxidation, slow boiling, boiling at the end of the heat and the highest possible temperature were tried. No relationship between the silicon content in ferrosilicon and watt loss was observed. The best results were obtained by pouring molten metal from the ladle into the furnace and by substituting calcium silicide for part of the ferrosilicon. The amount of calcium silicide was about

33% of the total silicon in the steel. Twenty-five melts in an 8-ton electric furnace and three melts in a 20-ton O.H. furnace in which the above method was used gave satisfactory results. The decrease in watt losses of about 0·5 W. per kg. was obtained. Another advantage of this method was that sheets of low watt losses had good permeability when placed in a magnetic field of low intensity—V. G.

Simplified Control Curbs Arc Furnace Power Appetites. (*Steel*, 1954, **135**, Aug. 23, 108–111). The Whiting Corp's "Hydro-arc" system of electrode movement control is described. The extremely fast response is very advantageous.

Arc Furnace Transformers. Constructional Characteristics and Their Effects on Capacity. A. Tagliaferri and P. L. Oliva. (*Met. Ital.*, 1954, **46**, July-Aug., 267–276; Oct., 354–372). [In Italian]. The authors review the principles governing the design of electric arc furnace transformers and describe the properties and operating characteristics of the various types of transformer in relation to the furnace performance. The need for keeping windings symmetrical to counteract the electrodynamic stresses set up by short-circuiting the furnace electrodes in the bath is stressed.—M. D. J. B.

Transformers for the Steel Industry—Transformer Materials. D. C. Graham and L. R. Bronlund. (*Iron Steel Eng.*, 1954, **31**, Aug., 118–124). The authors describe the improvements in electrical and structural steel which have contributed to the development of transformer design. The properties of core steel, the design of core and coil clamping structure, tanks for housing core and coils, fabrication techniques, and the handling of transformers are described.—M. D. J. B.

Transformers for the Steel Industry—The Application of Transformers in the Steel Industry. L. G. Levoy. (*Iron Steel Eng.*, 1954, **31**, Aug., 124–128). This paper deals with the application of power transformers, transformer standardization, the relative merits of three-phase and single-phase transformers, transformer cooling and insulation, and the application of power transformers to existing and to new systems.—M. D. J. B.

Transformers for the Steel Industry—Power Transformer Preventive Maintenance in the Steel Industry. E. A. Elge. (*Iron Steel Eng.*, 1954, **31**, Aug., 128–135). The author discusses the maintenance of power transformers. The influence of atmospheric conditions and the operation and maintenance of old and modern power transformers of different types are dealt with. The problems of minor repairs and failures are examined.—M. D. J. B.

On the Outline of Amplidyne Type Electrode Regulator. S. Miyazaki and S. Hazumi. (*Tetsu to Hagane*, 1952, **38**, Nov., 961–964). [In Japanese]. The first Japanese automatic electrode regulator of amplidyne type, for arc furnaces, has been installed at Adachi Steel Works by the Tokyo Shibaura Electric Co. A description and operating results are given.

Removal of Copper from Iron–Copper–Carbon Alloys. F. C. Langenberg and R. W. Lindsay. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Sept., Section 1, 967–968). Two methods of removing copper from liquid iron–carbon alloys, involving treatment with lead or with solvent Na_2S slags, are briefly discussed, and preliminary results obtained with both methods at the Pennsylvania State University are presented.—G. F.

Production Vacuum Melting—A Step Forward. H. E. Trout. (*Blast Furn. Steel Plant*, 1954, **42**, Sept., 1066–1068). A short illustrated account of the operation and utilization of the vacuum melting of steel is presented.—B. G. B.

Development of Induction Stirring. E. G. Malmlow. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 11–21). The author outlines the development of the ASEA (Swedish General Electric Co.) induction stirring equipment for use with electric furnaces, and discusses the principles of its operation. He describes the stirrer and its auxiliary equipment, and considers its possible application in other steelmaking processes.—G. F.

Details of Timken Induction Stirrer. Q. Graham. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 22). The author briefly describes the Timken induction stirrer, dealing mainly with the magnetic core, the winding and its cooling system, and the power supply.—G. F.

Rotating Magnetic Stirrer for the Arc Furnace. E. H. Browning and M. F. Jones. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 23–29). The Westinghouse rotating magnetic stirrer was originally designed for the holding ladle at the Babcock and Wilcox continuous-casting plant. The stirring device and the experimental holding ladle are described and the results of experimental tests given. Their success led to the application of the rotating stirrer to arc furnaces, and details of the equipment are given. The stirring motion caused by moving a magnetic field through a molten metal is discussed in an appendix.—G. F.

Manufacture of High-Temperature Alloys for Jet Engines. S. B. Batdorf and A. W. Hoppe. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 54–68). The authors consider some high-temperature alloys commercially used in jet engines as wrought or cast materials. The melting practices discussed are the direct arc, induction, and Kellogg processes, and the phenomena involved in the casting and solidification of the alloys, both as ingots and as castings, are described. The principles underlying the working of the ingots and heat-treatment of the component parts are discussed.—G. F.

Slag Treatment for Conservation of Chromium. T. W. Merrill and F. St. Vincent. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 69–73). In the production of ferrochromium, large slag volumes, of the order of 2½–3 tons per ton of metal, are produced with chromium contents of 4–8%. The authors discuss methods of increasing the chromium recovery and indicate the benefits of a repouring method in which the slag and metal are tapped into a ladle and then poured back into the furnace.—G. F.

Deoxidation and Its Effects on the Physical Properties of Steel. C. F. Christopher. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 101–115). The author discusses the characteristics of iron oxide in steelmaking furnaces, and considers the application of thermodynamic relationships to practical steelmaking operation. Different methods of making and deoxidizing acid open-hearth heats of low, medium, and high carbon steels are described.—G. F.

Sulphide and Oxide Formation in Steel. W. Crafts and D. C. Hilty. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**. 121–145). The authors discuss the mechanism of inclusion formation in the light of recent observations and consider some anomalies observed in practice, particularly with respect to the effects of initial oxygen content on inclusions. The Fe–Mn–S system and its modification by manganese, aluminium, and silicon are studied in detail.—G. F.

New Developments and Trends in Design and Operation of Electric Furnaces. W. E. Lewis. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 164–174). The author discusses recent trends in electric furnace design, dealing chiefly with mechanical improvements, electrical advances, and developments in electric counterbalancing.

New Developments in Electric-Arc Furnace Design and Operation. C. W. Vokac. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 174–178). The author gives details of the new Whiting electrode control and discusses its advantages. In this system the electrode motors do not reverse; one motor is constant-speed and the other varies its speed according to the amount the arc is off balance. The difference in speeds controls the level of an oil column, raising or lowering the electrode.—G. F.

Developments in Arc Furnace Design and Operation. E. A. Hanff. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 178–180). The author draws attention to recent developments in electric furnace design, particularly in the electrical equipment, and in the working conditions and safety aspects.—G. F.

Design, Operation, and Maintenance of Modern Large High-Powered Electric Arc Furnaces. G. D. Lawrence. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 187–192). The development of the electric process has necessitated the design of larger, more complex furnaces of higher power. The author reviews some problems of design, operation, and maintenance which have arisen, and considers possible solutions.—G. F.

Electric Furnace Maintenance. C. Hesselman. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 192). The use of cast brick in electric furnace hot spot areas at Newport Steel Corp. has increased production by five heats per furnace per month. Brief details are given.—G. F.

Comparative Melting Rates of an Elliptical Six-Electrode Furnace and a Circular Three-Electrode Furnace. J. K. Preston. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 194–198). For more than 20 years, the Timken Roller Bearing Co. has operated a 100-ton six-electrode elliptical electric furnace. The author compares operating data from this furnace with data from a modern circular three-electrode furnace of about the same capacity producing the same grades of steel. The six-electrode furnace requires a lower power input for the same melting rate.—G. F.

Solidification of Steel in Ingot Molds. L. H. Nelson. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 226–241). The author reviews his earlier data obtained from ingot-decanting experiments, and similar data from other investigators. In the earlier stages of solidification, the thickness (d) frozen transversely is related to time (t) by the well-known equation $d = K\sqrt{t} - C$ (K and C being constants). In the later stages, transverse solidification is often accelerated by the influence of vertical solidification, which is the dominating factor in determining the time of complete solidification. The author finds that the height (h) solidified vertically is related to time (t) by the equation $h = mt^3 + b$ (m and b being constants). The author studies the effect of ingot cross-sectional area, height/width ratios, and mould-area/ingot-area ratios, on the progress of solidification, and derives equations involving these factors from which the complete solidification time and the value of the constant K can be determined; they also show whether a particular ingot completes its solidification transversely or vertically. The data refer to wide-end-up hot-topped ingots.—G. F.

Nitrogen in Stainless Steel. H. P. Rassbach, E. R. Saunders, and W. L. Harbrecht. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 244–256). The behaviour of nitrogen during the melting of stainless steels was investigated with the object of improving the production of high-nitrogen stainless steels. Previously published laboratory data are compared with the results of induction heats, experimental arc furnace heats, and commercial heats. The solubility of nitrogen in iron containing chromium, manganese, or nickel, and the influence of temperature, are discussed.

Inclusions in Steel from Pouring Refractories. D. J. Carney and E. C. Rudolphy. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 274–280). The sources of large macroscopic inclusions in steel have been studied. Chemical and mechanical erosion, particularly of the nozzle, are major sources of these inclusions, and the use of TiO_2 as a tracer material confirms this. Recommendations to minimize these sources of inclusions are given.—G. F.

Sulphur Control in Electric Furnace Steelmaking. B. R. Queneau and C. V. Klimas. (*Amer. Inst. Min. Met. Eng., Proc. Elect. Furn. Steel Conf.*, 1953, **11**, 281–289). With high slag basicity, low oxygen level, and intimate mixing of slag and metal, extremely rapid desulphurization of steel is possible. The authors discuss the effects on desulphurization of carbon content, lime addition, time under reducing slag, and total sulphur in the system. The method of calculating the required weight of slag is outlined.—G. F.

The Electrical Dissociation of Fusible Slags and Its Use in the Determination of Slag Basicity. K. Werner. (*Met. u. Giesserei Techn.*, 1954, **4**, Sept., 379–384). In binary systems such as $CaO–SiO_2$ it is possible to determine basicity from measurements of electrical conductivity in the liquid phase, but the addition of a third component so affects the electrical conductivity of slag that simple conductivity measurement is inadequate. In practice, the composition of slags is neither binary nor ternary, but constitutes a mixture of many electrolytically dissociated components each affecting the electrical conductivity of the slag so that measurement of conductivity will not, by itself, give an indication of basicity.

Thermal Dissociation of Sulfur Dioxide and the Dissociation Energy of SO and S_2. G. St. Pierre and J. Chipman. (*J. Amer. Chem. Soc.*, 1954, **76**, Oct. 5, 4787–4791). The ratio $j = Fe^{3+}/(Fe^{3+} + Fe^{2+})$ in CaO–FeO slags in equilibrium with SO_2 or SO_2–CO mixtures is used to determine the partial pressure of oxygen in the gas at 1550° C. The products of dissociation of SO_2 at this temperature are principally SO and oxygen. The data lead to a decision between possible values for the dissociation energies of SO and sulphur in favour of 5·146 and 3·6 e.v., respectively. The free energies of formation of SO from sulphur and oxygen at 298·16 and 1823° K., respectively, are −18·6 and −20·6 kg.cal./mole.—R. A. R.

Investigation of the Properties of Components of Molten Slags Using an Electromotive Force Method. O. A. Esin and B. M. Lepinskikh. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1954, (2), 60–66). [In Russian]. The e.m.f. of concentration cells without transfer has been measured at 1470° C. Slags of the $CaO–MgO–Al_2O_3–SiO_2$ system were used as electrolytes. On the basis of the data obtained, the activities of (CaO + MgO), Al_2O_3 and SiO_2 and changes in the isobar potential on dilution have been calculated. The amphoteric behaviour of Al_2O_3 is shown and the presence in the liquid slag of anions of the compounds Ca_2SiO_4, $CaSiO_3$, $Ca_5Al_6O_{14}$ and $Ca_2Al_2SiO_7$ is confirmed. The possibility of applying the e.m.f. method to the control of the composition of liquid slags in metallurgical furnaces is experimentally determined.—V. G.

Contributions to the Data on Theoretical Metallurgy. J. P. Coughlin. (*U.S. Bur. Mines Bull.* 542, 1954). The heat and free energy of formation data for over 170 inorganic oxides obtained from a survey of the literature up to September 1953 are compiled. The oxides include all those associated with iron and steel making.—B. G. B.

The Heats of Formation of Manganous Orthosilicate and Manganous Sulphide. J. H. E. Jeffes, F. D. Richardson, and J. Pearson. (*Trans. Faraday Soc.*, 1954, **50**, Apr., 364–370). The heats of solution of manganous orthosilicate, quartz, manganous oxide, and manganous sulphide in hydrofluoric acid have been measured. The heats of formation of manganous orthosilicate and manganous sulphide were found to be −11,770 ± 700 cal. and −49,490 ± 310 cal. at 298° K. respectively. Details of the calorimeter used are given.

Industrial Application of the Process of Continuous Casting to Special Steels. Seloron. (*Centre Doc. Sid. Circ. Inform. Tech.*, 1954, (7), 1341–1353). Foreign trials of continuous casting are briefly reviewed, after which results at the Jacob Holtzer steelworks in France are described. In spite of the small output (1 ton/hr.) the process is economically justified for special steels owing to the reduction in metal wastage and savings in costs.—A. G.

Changes in the Composition of Metal and Slag During Casting in the Ladle. Achard. (*Centre Doc. Sid. Circ. Inform. Tech.*, 1954, (8), 1527–1535). On the basis of experiments with slags of various compositions an initial slag with maximum FeO and MnO_2 contents of 0·6% and 0·5% respectively, and at least 20% silica is recommended to minimize changes in metal composition. The difficulty of obtaining representative samples is stressed.—A. G.

The Determination of Sources of Non-Metallic Impurities in a Ball-Bearing Steel, Using Radioactive Calcium. V. A. Grigoryan and A. M. Samarin. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1954, (3), 91–101). [In Russian]. During the melting of steel in a high-frequency induction furnace, the basic lining of the crucible was not a source of impurities. Only when the bath was highly oxidized were non-metallic impurities from the basic lining present, when they accounted for about 12% of the total impurities. Slags of the reducing period of melting in furnaces with acid or basic linings and the basic slag from an induction furnace do not introduce impurities into steel either during the melting process or in the simultaneous transfer of slag and metal into a ladle. During the bottom casting of steel, 9% of the total impurities were introduced from refractories or casting equipment. Erosion of the transfer ladle introduced 18% of the total impurities.—V. G.

Production of Free-Cutting Steels. W. Bading and H. Riedel. (*Stahl u. Eisen*, 1954, **74**, Sept. 23, 1300–1303). The continued increase in the sulphur content of rimming free-cutting steels demanded by the user has led to great difficulties in their production. The effects of chemical composition on ingot surface defects and hot shortness during rolling are discussed. It is suggested that sulphur limits in current specifications could be lowered with advantage to the maker and to the user.—J. P.

Trials with Exothermic Feeder Heads. Venard. (*Centre Doc. Sid. Circ. Inform. Tech.*, 1954, (7), 1307–1314). The effect of feeder heads of different design with linings containing an exothermic material has been investigated on bottom-cast ingots. A reduction in metal wastage is achieved but the technique is costly and requires careful control.—A. G.

Solidification of Steel Ingots. Duflot. (*Centre Doc. Sid. Circ. Inform. Tech.*, 1954, (6), 1109–1112). Published American results on the solidification of metals and alloys are compared with those obtained by IRSID in tests on rimming, semi-killed and killed steels. Factors studied by IRSID include the rate of solidification, the formation of blowholes, the role of carbon content, and the segregation of copper, manganese, and sulphur.—A. G.

The Occurrence of Subcutaneous Blowholes in Narrow-Top Ingots for the Production of Tyres. A. Schubert, G. Wycisk, and H. Scholte. (*Met. u. Giesserei Techn.*, 1954, **4**, Aug., 372–374). The causes of subcutaneous blowholes are discussed and methods of prevention are suggested. Control of tyre production at the VEB steel plant Gröditz, based on empirical and theoretical considerations, is described.—L. J. L.

On the Rimming Action. I. Solidification of Rimming Steel Ingot. S. Ishihara. (*Tetsu to Hagane*, 1954, **40**, Apr., 403–413; May, 487–493). [In Japanese]. Results from the examination of many small ingots were plotted, and, from the curve, an equation was deduced, giving the ratio of the concentration of an element in the solid to that in the liquid in terms of the distribution coefficient, the degree of solidification, the rate of solidification, the value of the rimming action, and several constants. The rimming action strongly influences the effect of the enriched film and controls the entrapment of solute by dendritic crystals. This entrapment is greatly influenced by the solidification rate, particularly in the initial stages.

The Actual Importance of the Heterogeneity of Steel Ingots. B. Matuschka. (*Inst. Hierro Acero*, 1954, **7**, Apr.–June, 121–143). [In Spanish]. The author discusses the laws regulating the progress of solidification. The phenomena of contraction are then discussed. An account is given of shrinkage and shrinkage movements, vertical solidification, and means of counteracting shrinkage. A description is given of the physical mechanisms involved during solidification in the interior of the ingot.—C. B. L.

FOUNDRY PRACTICE

Engineering Research Methods and Casting Problems. A. W. Scott. (*Found. Trade J.*, 1954, **96**, June 24, 711–719, 722). In this Edward Williams Lecture, problems of common interest to engineers and foundrymen are reviewed with particular reference to those involving heat transfer and stress effects. The theoretical background of unsteady heat flow is outlined and results obtained on the freezing of benzene are compared with those for steel. Thermal stresses in solids are discussed together with thermal overstrain and the development and measurement of residual stresses.—B. C. W.

The Metallurgical Possibilities of Induction Melting Furnaces in Comparison with Other Furnace Systems. W. Goedecke. (*Giesserei*, 1954, **41**, Aug. 5, 405–410). Closed furnaces, *e.g.*, electric arc and graphite rod furnaces, are ideal for carrying out refining work. The employment of electromagnetic stirring of the bath can facilitate the slag reactions in induction furnaces and is thus important. Stirring is specially strong in low-frequency induction furnaces. The metallurgical processes in electric arc furnace, graphite rod furnaces, and medium-frequency and low-frequency induction furnaces are described and compared.—R. J. W.

Modern Techniques of Metal Melting. The Low Frequency Induction Furnace. F. Alvarez-Cascos Trelles. (*Inst. Hierro Acero*, 1954, **7**, July-Sept., 321–333). [In Spanish]. The evolution of the low frequency induction furnace is described; the equipment and layout of a modern unit is illustrated. Its advantages in the production of copper and aluminium alloys, and flake or nodular graphite cast irons are discussed and illustrated. Eight commercially manufactured low frequency furnaces are described.—P. S.

Induction Melting with High and Low Frequency. F. T. Chesnut. (*Amer. Foundryman*, 1954, **25**, June, 70–74). The principles and advantages of induction melting are outlined and the operation of the Wyatt and Tama-Wyatt submerged resistor furnaces is compared with that of the Northrup high-frequency furnace. The applications of each type of furnace are briefly considered.—B. C. W.

Progressive Induction Melting. E. von Kannen. (*Giesserei*, 1954, **41**, Sept. 2, 456–459). A description of the mechanical and electrical construction of low frequency coreless furnaces and low frequency crucible furnaces is given and the methods of operation are described. The methods are compared and illustrated.—R. J. W.

Indirect Arc Electric Furnaces of the ENS 40 and EN 40 Types. Z. Eminger and J. Nesnídal. (*Slévárenství*, 1954, **2**, (9), 257–265). [In Czech]. Two 80-kg. direct-arc furnaces were designed to replace imported high-frequency induction furnaces. The performance of the furnaces, one of them of the tilting type, up to operating temperatures of 1700° C. is described, and prices and operating costs of arc and high-frequency furnaces are compared.—P. F.

Gas and Oxide Contents of Cupola Iron, and the Effect of Charge Composition upon Them. P. Bardenheuer and P. von der Forst. (*Stahl u. Eisen*, 1954, **74**, Nov. 18, 1577–1582: *Foundry Trade J.*, 1954, **97**, Dec. 16, 715–719). The increased use of scrap, particularly steel scrap, in the cupola leads to various defects in the castings produced. An attempt has been made to correlate the gas and oxide contents of the charge with the defects occurring in the castings. The analytical methods employed are described. The main source of oxygen introduced into the cupola iron was the rust on the steel scrap. The oxide content of the cupola iron decreased to trace amounts when the charge consisted of rust-free steel scrap and ordinary pig iron. The effects of hydrogen and nitrogen are briefly mentioned.—T. G.

Improved Coke Cuts Cupola Operating Costs. S. W. Martin, B. W. Gamson, and T. G. Bowers. (*Iron Age*, 1954, **174**, Aug. 5, 97–99). The role of coke in a cupola charge is reviewed, and the effect of using a novel coke "Densite" is described. "Densite" is made in a slot oven using special ingredients (details not given); it has similar size and strength to normal foundry coke, but apparent density is 1·3, ash about 4%, and sulphur content low.—D. L. C. P.

Lining Basic Cupolas. E. Löbbecke. (*Giesserei*, 1954, **41**, Sept. 16, 477–485). The literature on the state of development of basic and neutral refractory materials is reviewed and the possibility of their use with and without cooling devices in cupolas is discussed. The behaviour of dolomite, magnesite, fireclay and carbon is considered. Ternary diagrams are given where applicable. Examples of the attack on fireclays are illustrated. Cooling devices for cupolas are illustrated. The design of tapholes and syphons and the materials used to make them are also considered. (52 references).—R. J. W.

The Cupola as a Hot Blast Generator. C. W. Pfannenschmidt. (*Giesserei*, 1954, **41**, Aug. 19, 437–439). The first cupola to be built for use with hot blast was constructed in 1925. The history of this type of plant is traced and the heat balances for cold and hot blast cupolas are compared. The production of foundry iron in a cupola with hot blast by direct treatment of iron ore is described, data on the composition of the slag, the melt, and the gas being given.—R. J. W.

Contribution to Slag Formation in the Cupola and to the Behaviour of Sulphur in Hot-Blast Melting. E. Piwowarsky and F. Hage. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, July, (13), 641–652). Equipment for measuring slag formation at different heights in a cupola is described and results are given for both hot and cold blast cupolas. The change in slag composition between the centre and wall of the cupola at different heights has been studied. The effect of atmosphere, slag basicity, and slag temperature on the FeO and MnO contents have been investigated. Experiments on the behaviour of sulphur in hot-blast melting are reported and the reactions occurring are discussed.—R. J. W.

Basic Lined Cupola Cuts Costs, Improves Quality. T. M. Frazell and J. D. Sheley. (*Iron Age*, 1954, **173**, Apr. 29, 85–88). After foundry trials with both acid and basic linings for a particular practice, the latter was found to give increased life and less refractory costs per ton melted. The basic slag can be controlled to provide desulphurization, limited dephosphorization and carbon pick-up; because of the latter, 100% steel charges can be employed.—A. M. F.

Desulphurization of Iron and Steel with Limestone from Tas-Kazansk. M. M. Turbovskiĭ. (*Liteĭnoe Proizvodstvo*, 1954, (5), 5–6). [In Russian]. The effects of a change in limestone quality on cupola operation and on the sulphur contents of various irons are described. The two limestones considered contained 84–92% and 97–98% calcium carbonate, respectively.—S. K.

Keeping Molten Iron Hot by the Use of Electrically Heated Ladles. E. Calamari. (*Fonderia Ital.*, 1954, **3**, June, 259–260). [In Italian]. A brief description is given of an induction heated

ladle for use in conveying molten iron from cupola to moulds in mechanized foundries. The ladle can keep 10 cwt. of iron at a constant temperature of 1350° C. using some 20 to 25 kW. It can also be used to bring molten iron to a temperature of 1750° C.—M. D. J. B.

Use of Agglomerated Iron Turnings in a Cupola. M. Ya. Gol'dshtein and M. L. Rabinovich. (*Liteĭnoe Proizvodstvo*, 1954, (5), 27). [In Russian]. A brief account is given of the production and use in the cupola of iron briquettes made by sintering iron turnings with sawdust.—S. K.

21st International Foundry Congress. This Congress, organized by the Centro Fonderia della Associazione Italiana di Metallurgia under the auspices of the Comité International des Associations Techniques de Fonderie, was held at Florence from Sept. 19 to Sept. 26, 1954. The papers presented, excluding those on non-ferrous metals, were:

The Grain Size of Cast Iron. M. Ferry and J. C. Margerie. (*Preprint* 1). [In French].

The Manufacture of Marine Propellers with Particular Reference to the Foundry. J. M. Langham. (*Preprint* 2). [In English].

The Mechanism of the Ferritization of Grey Iron and Its Retardation by Means of Tin and Copper. A. De Sy, J. Vidts, and J. Van Eeghem. (*Preprint* 3). [In French].

Factors Determining the Microstructure of Ordinary Iron Castings. M. Barbero and D. Fortino. (*Preprint* 5). [In Italian].

Influence of Graphite Segregation on the Damping Capacity of Cast Irons. G. Gola. (*Preprint* 6). [In Italian].

Systematic Suppression of the Formation of the Ferrite Eutectoid. A. de Sy. (*Preprint* 7). [In French].

Changes in the Hot Oxidation of Pure Iron and Cast Iron. V. Montoro. (*Preprint* 8). [In Italian].

Mechanism of Solidification and Segregation in High-Phosphorus Cast Iron. M. Ferry and G. Aubrion. (Preprint 9). [In French].

Graphitization Anomalies and Inverse Chill in Cast-Iron Piston Rings for Internal Combustion Engines. P. Gallinaro. (*Preprint* 10). [In Italian].

Old and New Methods in the Moulding Shop. F. Grosser. (*Preprint* 11). [In German].

Feeder Heads for Castings in Sand—Derivation of Practical Formulæ. R. Namur. (*Preprint* 12). [In Italian].

The Importance of the Croning Shell Moulding Process in the Modern Foundry. F. Poelzguter. (*Preprint* 13). [In German].

Cesare Brunelli and His Invention: The Italian Strainer (Pouring through a Strainer without Using Risers). G. Somigli. (*Preprint* 14). [In Italian].

The Layer Method—A Method for Determining Pouring Rate and Mould Orientation in Casting Steel. S. H. C. Forslund. (*Preprint* 15). [In English].

Homogenizing Steel Castings and Forgings. A. Hencks. (*Preprint* 16). [In French].

Cause and Suppression of the Formation of Rim Pearlite in Black Heart Malleable Iron. A. Bordes. (*Preprint* 17). [In English].

The Sulphur Index (S)/[S] As a Function of the Components of the Slag in the Metallurgical Blast Cupola. J. Drachmann. (*Preprint* 18). [In English].

The Cupola Combustion Curve (Study of Combustion in a 300 mm. Cupola). J. N. Alcacer and J. A. de Andrés Jiménez. (*Preprint* 19). [In Spanish].

Production of Cast Iron for Ingot Moulds in the Basic Lined Cupola from Charges of Different Compositions. G. Bostolani, W. Demicheli, and C. Longaretti. (*Preprint* 20). [In Italian].

Combustion Processes in Shaft Furnaces, Particularly Cupolas, up to the Consumption of Oxygen. (*Preprint* 21). [In German].

Manufacture and Properties of Refractory Crucibles in Relation to Their Use in the Foundry. G. Somigli. (Preprint 28). [In Italian].

The Continuous Basic Hot-Blast Cupola. S. Tunder. (*Preprint* 31). [In German].

Oxidizing and Deoxidizing Cupolas. G. Tarocchi. (*Preprint* 32). [In Italian].

A New Mains-Frequency Induction Furnace for Melting Ferrous Alloys. E. Calamari. (*Preprint* 33). [In Italian].

Thermal Stability of Spheroidal Graphite Iron. H. Timmerbeil. (*Preprint* 34). [In German].

Iron for the Production of Spheroidal Graphite Iron. R. Zoja and A. Masi. (*Preprint* 35). [In Italian].

Study of Some Austenitic Cast Irons with Spheroidal Graphite. J. Grilliat. (*Preprint* 36). [In French].

Mechanical Properties of Italian Spheroidal Graphite Irons with Particular Reference to Impact Strength. (*Preprint* 37). [In Italian].

The Importance of the Elastic Properties of Spheroidal Graphite Iron in Engineering. C. Gianola. (Preprint 38). [In Italian].

Modernization of a Steel Foundry. V. Socci. (*Preprint* 39). [In Italian].

Effect on Production Costs of a Rational System of Storage and of the Mechanized Transport of Raw Materials in a Medium Sized Foundry. P. Tincolini. (*Preprint* 40). [In Italian].

The Systematic Classification of Cast Irons. A. Wittmoser. (*Preprint* 41). [In German].

New Proposals for the Standardization of Grey Irons. A. Collaud. (*Preprint* 42). [In French].

Microstructural Modification of Cast Iron When Enamelling. V. Montoro, E. Lossa, A. Giussani, and E. Giussani. (*Preprint* 43). [In Italian].

The Formation of an Oxide Film on Molten Iron. R. Merz and B. Marinček. (*Preprint* 44). [In German].

New Possibilities of Precision Iron Castings by the Lost Wax Process. H. J. Meerkamp van Embden. (*Preprint* 45). [In French].

The Importance of Experiments When Teaching Foundry Technique. L. Frede. (*Preprint* 46). [In German].

Tests Comparing Ingot Moulds of Iron from Acid and from Basic Lined Cupolas. G. Bortolani, W. Demicheli, and C. Longaretti. (*Preprint* 47). [In Italian].

Some Methods for Casting Anisotropic Permanent Magnets on an Iron Cobalt Nickel Aluminium Base. A. J. J. Koch and K. J. De Vos. (*Preprint* 48). [In English].

Action of the Ground Coat in the Enamelling of Cast Iron. V. Montoro. (*Preprint* 49). [In Italian].

Experiments with Ultrasonics on Test Pieces of S.G. Iron. A. De Sterke and A. Bordes. (*Preprint* 50). [In English].

Ultrasonics—Testing Materials in the Foundry. Parow-Souchon. (*Preprint* 51). [In German].

How Classifying the Causes of Casting Defects and a Statistical Analysis Reduced the Percentage of Rejects in a Foundry. G. Marilli. (*Preprint* 52). [In Italian].

Bihar Bentonites and Scope for Their Development. R. M. Krishnan and B. R. Nijhawan. (*Preprint* 53). [In English].

Heat Transfer Between Mould and Metal in Sand Moulds. J. S. Abcouwer and C. A. M. van der Linden. (*Preprint* 54). [In English].

Preliminary Note on the Definition of Foundry Coke. E. Ferrara and I. Meltzer. (*Preprint* 55). [In Italian].

Experiences in Shaft Furnace Operations. H. Schmidt. (*Giesserei*, 1954, **41**, June 24, 346–347). The importance of using high quality initial material for satisfactory cupola operation is stressed. For example, the coke must be low in ash and sulphur and a light grey in colour. Examples are given of the quantities of limestone to be added and also of the amounts of air blast. The initial firing and charging of the furnace are described, quantities being given for a cupola 33½ in. in dia. Difficulties encountered in operating such a furnace, and their causes, are described. A method of freeing a choked taphole is illustrated.—R. J. W.

Erratum

In the last abstract on p. 193 of the *Journal* for October, 1954, entitled "Hardened Cast Iron Rolls for Rolling Mills" the reference was incorrect. It should read (*Slévárenství*, 1954, **2**, (2), 34–43; (3), 72–74).

New Electrode Control. H. F. Arndt and R. J. Songer. (*Foundry*, 1954, **82**, May, 325, 333). Details are given of a method for controlling the electrode gap in rocking electric-arc furnaces by means of a magnetic amplifier which, through a small electric motor, adjusts one electrode to maintain a constant arc current. Reductions of 15% in melting time and 5% in power consumption are claimed for furnaces using the new device.—B. C. W.

Evolution of Gases Dissolved in Metals. D. P. Lovtsov. (*Liteĭnoe Proizvodstvo*, 1954, (5), 24–25). [In Russian]. The importance of the function of inclusions in metals as nuclei for the formation of gas bubbles was confirmed in the investigation described.—S. K.

Sulphur in Magnesium-Inoculated Cast Iron. A. D. Ushakov and A. I. Nisnevich. (*Liteĭnoe Proizvodstvo*, 1954, (4), 25). [In Russian]. The radioactive isotope of S_{35} was used to check the effectiveness of the ordinary chemical methods of analysis for determining sulphur in magnesium or cerium-inoculated cast iron. Sulphur was detected by the action of the isotope on photographic plates, and it was found that inoculation of the iron disturbed the homogeneous distribution of sulphur. On reheating inoculated iron to 1580° C., the sulphur-rich areas again dispersed. Corresponding chemical analyses showed the ineffectiveness, attributed to the formation of sulphide-carbide complexes, of such methods for sulphur in inoculated iron.—S. K.

Inoculation with Magnesium of Previously Oxidized Grey Iron. V. A. Zakharov. (*Liteĭnoe Proizvodstvo*, 1954, (4), 23–24). [In Russian]. A brief report is presented of experiments in which the utilization of magnesium during the production of spheroidal cast iron was increased from 5–10% to 43–70%. The procedure was to add 0·3–5·4% of mill-scale to the iron melted in a 100-kg. induction furnace and stir thoroughly for 2–5 min. before adding the magnesium and the ferrosilicon. The chemical compositions of the iron at various stages are tabulated. Microstructures showing the satisfactory spheroidal nature of graphite in the products are shown together with results of tensile and impact tests; the mill-scale additions had no deleterious effect on the mechanical properties.—S. K.

Effect of Inoculating Cast Iron with 75% Ferrosilicon on Its Graphitization. B. V. Stark and N. K. Nekrasov. (*Liteĭnoe Proizvodstvo*, 1954, (4), 18–22). [In Russian]. The effect of final additions of 75% ferrosilicon in various quantities on the structure of iron containing different amounts of carbon and silicon was investigated. The method consisted of comparing microstructures of inoculated and uninoculated synthetic cast iron of the same composition, melted under the least oxidizing conditions possible. The results obtained are interpreted in terms of cooling conditions and phase changes. In general, inoculation increased graphitization and favoured its segregation in flakes. The effect was greater the less the contents of carbon and silicon in the iron.—S. K.

The Production of High-Silicon Iron Castings. P. Holtzhaussen. (*Met. u. Giesserei Techn.*, 1954, **4**, Aug., 369–372). The peculiarities and problems of casting 15%-silicon iron are outlined. Rejects in some foundries amount to 50%, due to excessive melting and casting temperatures and to excessive silicon content. By keeping melting and casting temperatures strictly within the ranges 1290–1340° C. and 1220–1280° C., respectively, and using a master alloy containing 0·5–0·7% C, 14·5–16·0% Si, 0·3–0·4% Mn, 0·1% P, and 0·05% S, rejects were reduced to 24·5%.—L. J. L.

Spheroidization of Graphite in the Cast Iron Treated with Bismuth. M. Yamaki and S. Suseki. (*Tetsu to Hagane*, 1952, **38**, Aug., 537–540). [In Japanese]. Addition of bismuth caused a reasonable degree of spheroidization in iron when the carbon saturation degree approached 1·0, a large amount of manganese was present, and the iron solidified rapidly.—K. E. J.

Production of High-Strength Cast Iron by Inoculation with an Alloy of Magnesium and Ferrosilicon. V. P. Pavlov. (*Liteĭnoe Proizvodstvo*, 1954, (5), 3–4). [In Russian]. Two methods are proposed for inoculating cast iron with magnesium without removing the ladle from the runner. In the first method the ladle is provided with an iron lid which is placed under a hole in the runner, the shape of the lid being such that a chamber is formed between runner and ladle. The iron passes through the chamber which is connected to a fan for removing fumes. In the second, the iron from the runner enters the ladle through a slot in its iron lid, while the fumes are removed through a chamber which is permanently attached under the runner. In each case the alloy is introduced as an ingot on the end of an iron bar. The deposit of magnesia which quickly forms on the lid prevents adhesion of iron splashes.—S. K.

The Manufacture in Italy of Cast Iron with Spheroidal Graphite, Using Metallic Magnesium. C. Longaretti. (*Giesserei*, 1954, **41**, Aug. 5, 410–412). The work in Italy in this field is briefly reviewed. The treatment of cast iron with magnesium elektron chips and the devices used to introduce them into the melt are described. Specifications are given for the production manufacture of cast iron with spheroidal graphite and the economics of the process are considered.—R. J. W.

Simplification for Foundry Efficiency. J. Hunter. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1954, **5**, Oct., 416–440). The results obtained by the Association's operational research team, which has been functioning for three years, are described and discussed. The author considers the significance of statistical data based on visits to 240 foundries.—B. G. B.

Solidification, Feeding of Grey and Nodular Iron. R. P. Dunphy, C. G. Ackerlind, and W. S. Cellini. (*Foundry*, 1954, **82**, June, 108–115, 249–258). The different solidification mechanisms of flake and nodular graphite cast iron are discussed. In grey iron the graphite flakes form in contact with liquid so that the expansion resulting from the transformation may be partially relieved by displacement of liquid. The displaced liquid serves to feed any regions of shrinkage and may also be expelled through any open risers; if the risers are frozen over the casting expands under the internal pressure. In nodular cast iron the transformation to graphite takes place in a solid matrix so that no feeding is produced and the expansion only causes plastic deformation of the casting walls. These different freezing mechanisms mean that grey iron requires very small feeders while nodular iron needs the same size feeders as steel castings of the same shape and size.—B. C. W.

HEATING FURNACES AND SOAKING PITS

Heat Transfer in a Gas-Fired Furnace. S. J. Genna, E. J. Nolan, and A. A. Furczyk. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 527–536). The general problem of heat transfer in a gas-fired furnace is examined. A method of analysis is introduced for determining the contributions of the various modes of heat transfer. A particular furnace, gas-fired with non-luminous flames, is investigated in the temperature range of 1750–2110° F. The results indicate that approximately 80% of the heat is transferred by radiation from the furnace walls to the charge and the remainder by gas convection and gas radiation.—D. A.

Applying Radiant Heat. (*Indust. Gas*, 1954, **17**, Aug., 356–358). Various industrial applications of heating by radiation are discussed. A radiant panel capable of operating at 1500° C., designed by Radiant Heating Ltd., used for heating steel tubes 12 in. in outside and 9½ in. in inside dia. is described.—D. H.

A Multiple Soaking-Pit Installation. General Design and Instrumentation. (*Iron Coal Trades Rev.*, 1954, **169**, Sept. 17, 695–696). The design, layout, and instrumentation of the soaking pit installation included in the modernization of the Round Oak Steel Works Ltd., are described with some details of its performance.—G. F.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Short-Cycle Normalizing Co-ordinates Tube Mill Production. J. Kniveton. (*Iron Age*, 1954, **173**, May 6, 136–138). The Lone Star Steel Co., Texas, operates two high speed pipe mills, producing 350,000 tons a year of pipe, in sizes up to 16 in. in outside dia. To normalize the pipe at welding line speed, 240-ft. long radiant gas heating barrel furnaces heat the metal to 1650° F. in 66 sec. This has advantages in plant, operation, and metal condition over conventional equipment. The seven zones of each furnace have automatic temperature control, and the heat requirements are directly related to the throughput rate.—D. L. C. P.

How Heat Treating Improves Modern High Strength Irons. C. R. Austin. (*Iron Age*, 1954, **173**, June 10, 125–129). The correct application of conventional heat-treatment methods, to obtain the best properties from Meehanite iron castings is described.—D. L. C. P.

Controlled Atmosphere Furnaces. M. Chain. (*Mem. Soc. Ing. Civils France*, 1953, **106**, July-Sept., 459–492). A detailed account of both small and large furnaces for the heat-treatment of metals in a controlled atmosphere is given. The use of diagrams showing the equilibrium between iron oxide and CO–CO_2, and iron oxide and H_2–H_2O is explained. Details are given of methods of producing a controlled atmosphere on an industrial scale.—R. A. R.

The Heat-Treatment of Flat Material. G. Daniélou. (*Mét. Constr. Mécan.*, 1954, **84**, Oct., 757–761). An account of a furnace for the continuous heat-treatment of flat steel is given. The steel is heated to 800–950° C., cooled quickly, reheated to 800–950° C. and maintained at this temperature, cooled slowly to between 650° and 400° C., and cooled to room temperature. The steel flats are conveyed through the blast-furnace-gas-fired furnace on rollers.—B. G. B.

Heat-Treatment of Strip Steel after Heating in a Continuous Furnace and after Electric Resistance Heating. H. Stromberg and A. Pomp. (*Stahl u. Eisen*, 1954, **74**, Oct. 7, 1343–1358). Experiments have been conducted in which carbon steel strip was heated in a continuous electric furnace and by direct resistance heating, before being quenched and tempered. The results showed that it is possible to produce material as good as that from normal annealing treatment by raising the heating temperature and shortening the transit time. The relationship between line speed and temperature in the range 900–1150° C. is shown graphically for a number of steels. Direct electric heating is more efficient than normal furnace treatment.—J. P.

The Sulfinuz Process. (*Brit. C.I. Res. Assoc. Bull.*, 1954, **12**, Sept., 382–383). A short description of a patented sulphur cementation process is given. The process produces a self-lubricating wear-resistant surface on iron or steel without increasing the hardness of the metal.—B. G. B.

Versatile Production of Precision Parts. P. Trippe. (*Machinist*, 1954, **98**, Sept. 24, 1697–1702). Methods used by Aldis Bros. Ltd., and Aero Heat Treatments, Ltd., for the production of mass-produced parts are described. The latter company has the largest privately owned Cassel-I.C.I. salt bath plant in Europe; this is described.—M. A. K.

Just Spin Them in Salt. C. G. Lee. (*Machinist*, 1954, **98**, Aug. 28, 1518–1519). Selective hardening of gear teeth is carried out by spinning in salt baths, using a variable speed drive. The technique is fast and minimizes gear distortion.

The 'Quetten' Hardening Machines for Plates and Rolled Sections. H. Bühler. (*Z.V.D.I.*, 1954, **96**, Sept. 1, 839–841). Installations are described, which have been developed in Germany during the last 20 years for the quench-hardening of large plates and rolled sections such as joists. The distortion is prevented by clamping arrangements, illustrations of which are given. Clamping pressures ranging from 1·5–8 tons/sq. in.

Load Resistance and Efficiency of Energy-Transferring Units of Induction Heaters. H. Köpke. (*Elektrowärme-Techn.*, 1954, **5**, (8), 157–163). The damping of the oscillating circuit upon introducing steel specimens of various shapes was investigated experimentally and theoretically. The relationships between the distance of the specimen from the coil walls, the coil dimensions, the temperature of the specimen, and the frequency were studied, and these are represented by nomograms which are also applicable to energy-transfer calculations with coils and specimens of different dimensions, operating at various frequencies.—P. F.

Induction Surface Hardening of Ductile Iron. J. F. Libsch and J. C. Danko. (*Metal Progress*, 1954, **66**, Sept., 115–121). Ductile or nodular cast iron can be heat-treated by quenching and tempering, or isothermally, to give a structure containing considerable amounts of combined carbon. This structure can be case-hardened by rapid induction or flame heating to give a surface which has a hardness of Rockwell C–57 with a case depth somewhat greater than for steel.—B. G. B.

Rotaflame Burners Heat Rectangular Furnace. W. Trinks. (*Steel*, 1954, **135**, Sept. 13, 132–135). Small multiple burners firing into a large car-bottom rectangular annealing furnace, caused soft spots in the charge of large mill rolls, due to hot spots. Two large Urquhart burners firing from diametrically opposite corners along the longer walls caused the atmosphere to circulate and overcame the trouble. Temperature control is obtained by regulating the excess air.—D. L. C. P.

FORGING, STAMPING, DRAWING, AND PRESSING

Ultrasonic Testing Lowers Forging Production Costs. R. N. Hafemeister. (*Iron Age*, 1954, **173**, May 13, 117–120). Experience in ultrasonic testing of cold, medium, and large forging ingots, blooms, and forging at Allis-Chalmers Manufacturing Co. is reported. The information gained on the internal condition of each ingot has allowed the best forging procedure to be selected; cost savings have resulted. An account is given of the inspection programme and examples are cited.—D. L. C. P.

These Blades are Precision Forged at Bristol Aeroplane Co., Ltd. P. Trippe. (*Machinist*, 1954, **98**, Aug. 28, 1501–1508). A special precision blade-forging plant has been developed by Bristol Aeroplane Co. Ltd., to produce a wide variety of compressor and turbine blades required for development purposes. Blades are finished-forged to within a 0·0005 in. envelope. Electro-erosion methods are used, employing shell moulded electrodes, to renovate the forging dies quickly and economically.—M. A. K.

Hufford Carousel. (*Aircraft Prod.*, 1954, **16**, Oct., 426–428). A description is given of a new stretch-wrap forming machine which is capable of forming reverse bends and full circles.

Joining Thin-walled Parts by Rubber Forming. F. R. Simpson. (Amer. Soc. Tool Engineers: *Machinery*, 1954, **85**, Oct. 1, 709–714). A rubber-forming technique may, in certain cases have a definite advantage in providing leak-proof joints in thin-walled metal components. When properly supported, rubber can transmit pressures of the order of 30,000 lb./sq. in. which are sufficiently high to deform certain types of steel, brass, and other metal alloys.—M. A. K.

Travelling Pressure Shoe Extends Stretch Forming Uses. H. Hein. (*Iron Age*, 1954, **173**, May 20, 141–143). A useful addition to conventional rotating-die stretch-forming machines is described. This is a side pressure shoe which presses on the work where it is at a tangent to the die. In a further development a pressure shoe is able to operate at any point on the work with an ironing motion. These shoes enable tough alloys to be formed accurately with good retention of physical properties, and irregular shapes may be made.—D. L. C. P.

Metal Spinning—A Little-Known Method of Plastic Forming. A. Buzas. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, Sept., 275–277). A preliminary test to determine the suitability of material for spinning is described, and the economic advantages of spinning are outlined.—L. D. H.

Deep Drawing Properties of Sheet Steel, Fundamental Principles and Test Methods. O. Svahn. (*Jernkontorets Ann.*, 1954, **138**, (9), 573–610). [In Swedish]. A study was made of conventional test methods for determining material drawability, reproducibility, and correlation between methods, with the object of obtaining a drawability criterion and to study factors influencing material deep-drawing coefficients. Tests made on 10 steels showed that neither correlation nor reproducibility was possible. It was found that two cup test methods, both approximating closely to actual practice, merited study. Test results are given. (49 references).—G. G. K.

Relation Between the Thickness and the Cupping Properties of Deep-Drawing Steel Sheet. B. Otta. (*Hutnické Listy*, 1954, **9**, (8), 465–467). [In Czech]. The drawability of deep-drawing sheet 0·015 to 0·08 in. thick is calculated from the relation between sheet thickness and Erichson values. The results fall within the limits prescribed by Czechoslovak standard specifications.—P. F.

Deep-Drawing Tests on Thin Strip. A. Krisch. (*Stahl u. Eisen*, 1954, **74**, Nov. 18, 1591–1594). Steel and brass strip 0·1–0·4 mm. thick and 70 mm. wide were tested by the Erichsen cupping test to determine the necessary pressure of the blank holder to avoid the formation of wrinkles. The thinner gauges formed wrinkles outside the blank holder. These wrinkles assist in holding the strip and affect the results obtained. Higher cupping values were obtained with decreasing blank-holder pressure. When using tools with an overall diameter greater than the width of the strip, wrinkles ceased to form and more uniform and consistent results were obtained.—T. G.

Comparison of Different Lubricant Carriers for Drawing Stainless Steel Wires. H. Kuntze and A. Pomp. (*Stahl u. Eisen*, 1954, **74**, Oct. 7, 1325–1334). Drawing tests have been carried out on stainless steel wires coated with lime-salt, iron oxalate, or modified oxide carriers, and using calcium stearate as a lubricant. The application of the carrier coatings is described. The effectiveness of the lubricating systems was determined from the amount of wear on the dies, the coefficient of friction calculated from the drawing force, and the surface finish of the wires. The lime-salt and oxalate carriers were equally good but the modified oxide coating was very much inferior.—J. P.

The Influence of Lubricants on Drawing Force in the Drawing of Steel Bars. W. Lueg and K-H. Treptow. (*Stahl u. Eisen*, 1954, **74**, Oct. 7, 1334–1342: *Wire Indust.*, 1954, **21**, Dec., 1211, 1212, 1215, 1216, 1238). The force required to draw bars of carbon and Cr–Ni steel through tool steel and

carbide dies has been measured using lime, borax, alkali, graphite, polyisobutylene, silicone, iron or iron oxide in organic binders, and iron oxalate as lubricant carriers. The actual lubricants were rape seed oil, petroleum, ten different drawing oils, four drawing greases, graphite, molybdenum disulphide, polyisobutylene, and three silicone oils. In general, no combination was as good as lime plus rape seed oil for the unalloyed steel. Alkali with rape seed oil gave the lowest drawing force and the best surface finish on the stainless steel. The suitability of a drawing oil increases with its content of saponifiable matter, the flash point and viscosity having no relevance.—J. P.

Alloy Steel, Titanium Successfully Hot Extruded. K. A. Wilhelm and G. A. Moudry. (*Iron Age*, 1954, **173**, Apr. 29, 98–102; May 13, 126–129). An extensive and systematic study of the hot extrusion of alloy steels and titanium carried out by the Lockheed Aircraft Corp. is described. Extrusion limit, slenderness ratio, optimum temperature, heat-treatment, lubricants, and die design for nickel–chromium–molybdenum and stainless steels were studied. Good results were obtained with mechanical properties equal to or better than those of wrought materials. Titanium extrudes better than steel, but requires higher pressures; **T** and **H** sections were extruded at 1800° F. with satisfactory properties, and it is expected that cheaper production of aircraft structural parts will be possible.

An Experimental Study of Metal Extrusions at Various Strain Rates. J. Frisch and E. G. Thomsen. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 599–606). A 4½ in. dia. commercially pure lead billet was extruded at room temperature into a 1½-in. solid bar at extrusion rates of 0·1, 0·74, and 5·15 in./min. Particle velocities, magnitude, and direction, for the inverted extrusion process using a sharp-edged die were determined on a meridian plane by a stepwise extrusion method. For the rates investigated, the flow pattern was invariable with respect to the extrusion rates. Measured wall pressures increased approx. linearly with extrusion speed in a similar manner as extrusion load so that the ratio of applied pressure to wall pressure remained constant. The mean pressure within the metal differed from the measured wall pressure. The predicted mean pressure obtained from a graphical analysis of the velocity pattern of the billet agreed approximately with the measured mean pressure.—D. H.

Wire-Drawing Machines for Steel Wire. H. Richards. (*J. Iron Steel Inst.*, 1955, **180**, May, 60–65). [This issue].

Driving and Controlling Wire Drawing Machines. J. R. Erbe and H. A. Dickerson. (*Blast Furn. Steel Plant*, 1954, **42**, Sept., 1048–1052; Oct., 1169–1177). The construction and selection of motors for operating wire drawing machines are considered. The capabilities of various available drives and their relative costs are given in order to assist in the selection of wire-drawing machine drives.—B. G. B.

ROLLING-MILL PRACTICE

Use of Hydraulic Power in Rolling Mills. H. Castanié. (*Mét. Constr. Mécan.*, 1954, **84**, Sept., 665–669). The hydraulic lubrication of bearings in rolling mills is discussed, particular reference being made to the fluid bearing in which the lubricant is under high pressure.—B. G. B.

Bearing Cartridge Bolts for Roller Tables. J. I. T. Green and A. Conway. (*J. Iron Steel Inst.*, 1955, **180**, May, 34–38). [This issue].

Calculating the Through-Put Capacity of a Blooming Mill and of the Time Allowances for Each Shape and Pass, as a Basis for Setting up Incentive Wage Rates, and for Comparisons with Other Mills and Other Plants. J. Wolf. (*Stahl u. Eisen*, 1954, **74**, Dec. 2, 1652–1659). A detailed account is given of the use of punched cards for time studies of the various operations in a blooming mill. Examples are presented and discussed. The correlation of blooming mills and bar mills with a view to obtaining maximum efficiency of the whole plant is considered.—T. G.

New Combination Rod Mill Will Develop High Speed. A. F. Kenyon. (*Iron Steel Eng.*, 1954, **31**, Sept., 210–212). The article describes a new 25-stand rod mill, the first 15 of which operate as a continuous roughing and intermediate train, with automatic crop and cobble shears between the 9th and 10th stands. The mill will roll 3½ in. square billets 30-ft. long to rods 0·205 in. dia. and round bar up to 1⅛ in. in dia. at speeds up to 6500 ft./min.—M. D. J. B.

Two-High/Four-High Combination Mill Aids Rolling Research. A. I. Nussbaum. (*Iron Steel Eng*, 1954, **31**, Sept., 199–205). The author describes the two-high/four-high combination mill which is a high precision mill capable of performing a wide range of reduction on bar, rod, and strip at moderate cost and in a small space in laboratories.

Wire Flattening—A Lower Cost Narrow Strip Producer. A. I. Nussbaum. (*Steel*, 1954, **135**, Sept. 6, 104–109). A machine is described for producing narrow strip from wire, for making hair springs, slide fasteners, resistance elements, and suspension ribbons. Self-contained tandem mills are being increasingly used.—D. L. C. P.

Two-Stand Tandem Wire Flattening Mill. (*Engineer*, 1954, **198**, Oct. 8, 502–504). The article describes a high-speed, two-stand tandem rolling mill installed by an American manufacturer of zip fasteners for the production of close-tolerance narrow strip by "wire flattening" rather than by slitting wider strip. The mill rolls are 6 in. dia. by 4 in. wide and are each driven by 15 h.p. D.C. motors.—M. D. J. B.

Direct Rolling of Liquid Metals. C. Fritzsche. (*Technik*, 1954, **9**, Aug., 453–458). This is a review of American and Russian experiments relating to the Hazlett process and its modifications for the production of strip direct from molten metal. So far there are no prospects of the process being practicable with steel.—J. G. W.

Operating Variables and the Output of a Machine Rolling Special Sections from Cold Rolled Steel Strip. G. Thiel. (*Stahl u. Eisen*, 1954, **74**, Oct. 7, 1376–1377). A mathematical and graphical method is proposed by which output and efficiency of a mill shaping sheet metal into sections can be assessed from rolling speed, shearing time, length of cut section, coil joining time, and coil weight.—J. P.

Gamma Ray Thickness Gauge for Hot Steel Strip and Tubes. G. Syke. (*Brit. Steelmaker*, 1954, **20**, Sept., 364–369). A description is given of a prototype gamma-ray thickness gauge developed for measuring the thickness of hot-rolled steel strip between 0·05 in. and 0·30 in. The gauge uses a scintillation detector and provides distinct readings at short time intervals. Results are displayed on a lamp board, giving a visual picture of the profile. An adaptation gauging the wall thickness of hot steel tubes is also described.—G. F.

Develop New Method for Cold Rolling Splines. W. G. Patton. (*Iron Age*, 1954, **173**, June 24, 110–112). A type of machine employing a new method of forming splines, oil grooves, serrations, and similar shapes is described. The material is cold rolled and formed between two sliding forming racks. It is claimed to give superior quality with a high-output and no chip formation.—D. L. C. P.

Work Studies in Cold Rolling Mills. W. Scotland. (*Stah u. Eisen*, 1954, **74**, Oct. 7, 1358–1367). Time and motion studies in a cold rolling mill have indicated a convenient and satisfactory way of assessing wage rates and, with suitable office equipment, of establishing an efficient supervision system.—J. P.

MACHINERY FOR IRON AND STEEL PLANT

The Fastening of Crane Rails on Steel and Reinforced Concrete Crane Tracks. K. Eckinger. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1418–1424: *Iron Steel Inst., Translations Miscellaneous Series No.* 232). The stresses to which crane rails are subjected and the movements possible between rail and crane-way are considered. The various methods of fastening rails (bolting, riveting, clamping), and their advantages and disadvantages are described.—J. P.

The Play of Forces within the Joint between the Crane Rail and the Steel Reinforced Concrete Beam of a Crane Track. E. Kranz. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1424–1431: *Iron Steel Inst., Translations Miscellaneous Series No.* 229). To avoid failures in crane tracks there should be close co-operation between the designer and the concrete expert in the preparation of the plans and great care must be exercised during construction.—J. P.

Steel Crane Tracks for Iron and Steel Works. H. P. Witt. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1431–1437: *Iron Steel Inst., Translations Miscellaneous Series No.* 233). It is indicated how a heavily loaded crane-way for a steelworks should be planned. The different shapes of rail in use in Germany, America, and Britain are compared. Recommendations are made on securing the rails.—J. P.

Operating Experiences with Gas Turbine Plants in the Steel Industry. H. Pfenninger. (*Blast Furn. Steel Plant*, 1954, **42**, Aug., 942–944, 947, 950; Sept., 1076–1079). The use of natural gas and blast-furnace gas as a fuel for gas turbines is first considered. The successful performance of a gas turbine at a steelworks at Dudelange, Luxembourg, which uses either of these gases and is designed for generating electrical power and compressing air is described in detail. Operating data from a gas turbine installation at the Baracaldo steelworks in Spain for compressing air for Bessemer converters are also discussed.—B. G. B.

The Selection, Operation and Maintenance of Industrial Steam Shunting Locomotives. (*Mech. World*, 1954, **134**, June, 255–258; July, 314–318; Aug., 357–359; Sept., 402–407). An analysis is given of the duties of steam locomotives within works' premises. The performance and facilities offered by modern motive power units are discussed. Particular attention is given to data and information required in selecting suitable equipment.—D. H.

LUBRICANTS AND LUBRICATION

Steel Mill Lubrication Problems. A. C. Keiser, jun., E. E. Perso, W. H. Mandy, and M. S. Clark. (*Iron Steel Eng.*, 1954, **31**, Sept., 177–182). The authors describe the severe conditions under which lubricants must operate in steel mills, particularly with water and mill scale contamination in hot and cold strip mill bearing-oil systems.—M. D. J. B.

Planned Lubrication at The Steel Company of Wales. H. Harber. (*Sci. Lubrication*, 1954, **6**, Aug., 10–13; Sept., 12–15). An account is given of the organization of the Lubricant Department and the system of storing and distributing the lubricants, which are standardized in grades as far as possible. Details are given of the routine testing equipment and procedure for lubricants at Margam. The blast-furnace plant has centralized grease lubrication equipment.—K. E. J.

Factors Affecting Performance of High Temperature Greases. E. L. Armstrong. (*Iron Steel Eng.*, 1954, **31**, Sept., 167–174). The author defines the temperature ranges within which various greases can be used. The temperature ranges for solid lubricants such as graphite and molybdenum disulphide are also indicated.—M. D. J. B.

Silicone Greases. A. Richard. (*Usine Nouvelle*, 1954, **10**, Sept. 16, 55–59; Sept. 30, 57–59). The general chemical and physical properties of silicones are summarized. Silicone greases are exceptionally heat resistant, certain of them functioning satisfactorily for long periods at 250° C. They have a low volatility; their consistency varies only slightly with temperature, and they are very resistant to oxidation. The properties of greases in the temperature ranges − 75° to + 150° C., and − 30° to 260° C., are discussed with the aid of tables.—T. E. D.

WELDING AND FLAME-CUTTING

Applications of Welding and Allied Processes in the Construction and Maintenance of the French National Railway Tracks. (*Soudure Techn. Connexes*, 1953, **7**, Mar.-Apr., 87–100).

I—The Question of Long Sections of Welded Rails. O. Leduc. (87–91). Very long lengths of rail reduce the number of joints, cause smoother running, and increase the life of rolling stock. Wood and concrete sleepers with various types of rail attachment are discussed, and the use of angular joints to allow for thermal expansion is mentioned. Lengths up to 800 m. are used satisfactorily.

II—Thermit Welding of Long Sections of Welded Rails, and the Various Applications of Thermit Welding. C. Naffrechoux. (92–100). Two methods of joining rails are described. In the first, the mould surrounding the two rails is filled only up to the top of the web of the rails, and then the two rails are pulled together by a heavy clamp. Thus the base and web of the rails are welded, and the tops are forged. In the second method, the two rails are surrounded by the mould and preheated to 800° C. by gas, petrol or oil burners. They are then thermit welded across the whole section. The merits of the two methods are discussed. Tests on rails are described.—T. E. D.

Studies of the Electric Arc in an Argon Atmosphere. J. Brillié. (*Soudure Techn. Connexes*, 1954, **8**, July-Aug., 195–204). High speed ciné-photography has been used to study the electric arc in argon. The consumable wire electrode method of welding with reversed polarity, in which the wire is unrolled very rapidly, transfers metal in small droplets because of the high current density. Applications of argon-arc welding to steels and non-ferrous metals are discussed.

Rebuilding Steel Mill Rolls. R. Hall. (*Iron Steel Eng.*, 1954, **31**, Sept., 109–112). The author describes special equipment for re-metalling rolls by arc welding. The method is economic and it is claimed that the rebuilt rolls are at least equal to new rolls.—M. D. J. B.

Economical Roll Reclamation. J. Goldstein. (*Iron Steel Eng.*, 1954, **31**, Sept., 112–114). The author describes the automatic submerged arc welding process for reclaiming rolls, in which the welding takes place beneath the melt thereby concealing the arc. Repairs to table rolls and pinch rolls are described.—M. D. J. B.

MACHINING AND MACHINABILITY

The Theory of the Influence of Hexagonal Elements and Compounds in Polycrystalline Structures. A. Paudrat. (*Métaux—Corrosion—Indust.*, 1954, **29**, Sept., 315–334; Oct., 372–379). The influence of sulphur and lead on the speed of machining steels is described and the reasons for the change in cutting properties are considered. The influence of inter- and intra-crystalline forces on the strength of polycrystalline metals is reviewed, with particular reference to machining. Industrial methods of sulphur cementation and sulphur-nitriding and their effect on the properties of steels are reported. (34 references).—B. G. B.

Influence of Sulphur on the Machining of Steels, As It Affects Cutting-speed and Tool Wear. A. Paudrat. (*Génie Civil*, 1954, **131**, Nov. 15, 433–434: *Compt. Rend.*, 1954, **239**, Oct. 11, 879–880). The usual explanations of the free-cutting properties of sulphur-bearing steels are questioned. An alternative hypothesis is suggested linking the lubricating properties of sulphur to its crystalline state or its presence as iron sulphides with sulphur in excess of that in FeS. Processes are briefly described for introducing sulphur into steels to make them free-cutting and into cutting tools to increase their wear resistance.—G. E. D.

Mullard Ultrasonic Drill for Machining Hard Materials. (*Machinery*, 1954, **85**, July 30, 231–232: *Metallurgia*, 1954, **50**, Sept., 137–138). A 50-W., and a larger 250-W. ultrasonic drill developed by Mullard Research Laboratories are described. Both machines, with the aid of suitable tools can, in addition to drilling, be used for cutting, shaping, hobbing, grinding, and polishing.—M. A. K.

SKF Bearings in New Machines for Surface Machining Alloy Steel Ingots and Billets. (*Ball Bearing J.*, 1954, (1), 22–28). Two machines are described, one a milling machine fitted with sintered carbide cutters, the other a grinding machine.

Hot Machining. H. Laplanche. (*Mét. Constr. Mécan.*, 1954, **84**, Sept., 659–662). The mechanical properties of steel decrease with increase in temperature and it is possible to machine steels at an elevated temperature which are difficult to machine at room temperature. This technique for machining steels and high-temperature alloys is described.—B. G. B.

CLEANING AND PICKLING

A New Method of Pickling Special Steels. E. Calamari. (*Ing. Mecc.*, 1954, **3**, June, 22–24). [In Italian]. A description is given of the sodium hydride pickling method developed by Du Pont De Nemours with details of the chemical reactions which takes place. The author also describes a large installation for the treatment of stainless steels.—M. D. J. B.

Glossary of Terms Used in Metal Cleaning and Finishing. (*Iron Age*, 1954, **174**, July 29, F49–F65). An alphabetical list of 113 terms used in the fields of metal cleaning and finishing is given, and the significance of each explained.—D. L. C. P.

Handling Metal Finishing Wastes. A. M. Reed. (*Products Finishing*, 1954, **18**, Sept., 53–60). The activities of a committee of the Ohio River Valley Sanitation Commission in dealing with water pollution are reviewed.—A. D. H.

De-Scaling by the Sodium Hydride Process. (*Railway Gaz.*, 1954, **101**, Oct., 433–434). A short description is given of a sodium hydride descaling plant at Staines for use as a contracting service for the engineering industry and allied trades. The process is claimed to descale effectively most metals including all grades of stainless, heat-resisting, high-speed, structural alloy, carbon, and mild steels.—B. G. B.

Two New Results Relating to the Composition of Electropolishing Baths. P. Brouillet and I. Epelboin. (*Rev. Mét.*, 1954, **51**, Oct., 693–701). After reviewing the optimum conditions for electropolishing and the Darmois theory of electrolysis the following two results are stressed: (1) The analysis of conductivity measurements for confirming the existence of an anhydrous layer near the electrode; and (2) an application of this study to the polishing of materials which are difficult to machine.—A. G.

PROTECTIVE COATINGS

New Coatings Resistant to Shock and Corrosion. (*Usine Nouvelle*, 1954, **10**, Oct. 7, 27). Coatings with epichlorhydrin resin bases are now manufactured in France. The properties of four classes of coatings are outlined: (1) Coatings baked at high temperatures (170–210° C.); (2) coatings baked at lower temperatures; (3) coatings hardened by polymerization at ordinary temperatures; and (4) Coatings air-dried by oxidation.

Neat Gas Burner Applications of Finishing Interest. A. E. Wilson. (*Indust. Finishing*, 1954, **7**, Aug., 60–65, 69). Applications of post-aerated burners up to 1000° F. are cited; these are for heating solutions of degreasers, phosphate solutions, and other liquids, forced convection, heating chemical vessels and pans, galvanizing baths, and various standard boilers and ovens.—K. E. J.

Thermal Radiations and Surface Coatings. K. Magnusson. (*Paint Manufacture*, 1954, **24**, Aug., 255–257). The absorptivity and reflectivity of a number of surface coatings have been studied. These experiments also include a method for the measurement of thin films of coatings. Particular attention is given to aluminium paints.—L. E. W.

The Mechanism of Reversed Current Electrolysis. J. Elze. (*Metall*, 1954, **8**, Sept., 699–700). A study of the mechanism of electrolysis by the reversed current method has revealed that the resulting higher quality of deposition is due principally to the processes occurring during the brief anodic phases of the method.—J. G. W.

A Magnetoinductive Meter of High Sensitivity and Large Range of Measurement for the Determination of Layer Thicknesses. R. Berthold. (*Metalloberfläche*, 1954, **8**, Aug., A117–A119). An instrument is described for the determination of the thickness of non-magnetic layers on a magnetic base. Methods of standardization, and the influence of the dimensions and magnetic properties of the base material are discussed.—L. D. H.

The Determination of the Thickness of Thin Metallic Layers, Using the Temperature Coefficient of Resistance. S. Tunakan. (*Revue Fac. Sci. Univ. Istanbul*, 1954, **19c**, Jan., 15–**22**). [In German]. The thickness of metallic layers which are not too thin can be evaluated from $d\rho/dt$ if the change of resistance is reversible over a certain range of temperatures. It is assumed that $d\rho/dt$ is the same as that of the metal over the range of temperatures dealt with. (ρ is the specific resistance and t the temperature.)—R. P.

O.N.E.R.A. Processes of Thermal Chromizing and the Heat-Treatment of Chromized Steels. P. Galmiche. (*Rev. Mét.*, 1954, **51**, July, 489–497). After an outline of the principle and equipment of the O.N.E.R.A. (Office National d'Etudes et de Recherches Aeronautique) processes of gaseous cementation with chromium, the conditions are described whereby thick corrosion-resistant layers or thin extremely hard layers of chromium carbides are produced. The problems associated with thermal chromizing and the influence of steel quality and conditions of treatment on the protection afforded are discussed. A few applications of the process are studied.—A. G.

"Integrated Chromizing": Combination of Simple Heat-Treatment with a Thermochemical Chromium Cementation Treatment. P. Galmiche. (*Rev. Mét.*, 1954, **51**, July, 498–502). Examples are given showing where chromizing may be combined with heat-treatment. These include the production of corrosion resistant parts with good mechanical properties from sintered iron, improving the resistance of refractory alloys to high temperature corrosion, and the bright annealing of oxidized parts.—A. G.

Chromium Plating of Large Rolls. M. E. Gol'dshtein. (*Stanki i Instrument*, 1954, (5), 33–34). [In Russian]. The simple technique of chromium plating described can be used for reclaiming rolls over 6 ft. 6 in. long. The portion of the roll to be plated passes through insulating and sealing flanges in the side walls of a small welded iron tank. The anode consists of two half-rings, perforated for easy escape of gas, which enclose the roll. Steel screens in the form of rings are fitted on the roll at each end of the plated zone to secure a fine crystalline deposit. After a brief period of passivation, deposition is carried out at 55–60° C. and a c.d. of 55–65 amp./sq. dm.—S. K.

Crack-Free Chromium Deposits. H. W. Dettner. (*Metalloberfläche*, 1954, **6**, May, B69–B73). Dow and Stareck's process (*see J. Iron Steel Inst.*, 1954, **176**, Feb., 235) for the electrodeposition of crack-free chromium is described in which a self-regulating bath at about 65° C., with a c.d. of 50 amp./sq. dm. is used. The absence of cracks was associated with a considerable increase in corrosion resistance, irrespective of the base metal.—L. D. H.

The Use of Semi-Automatic Plating Lines. T. Stoddard. (*Electroplating*, 1954, **7**, Sept., 336–338). The author describes a flexible installation, for chromium plating bathroom fittings. The process is claimed to give fewer rejects and to increase productivity.—A. D. H.

New Low-Cost Coating Gives Mild Steel Good Corrosion Resistance. G. J. Harvey. (*Iron Age*, 1954, **173**, Apr. 15, 125–127). A process for depositing any thickness of a high-nickel low-phosphorus alloy, called the "Niphos" process, has been developed. A combination of nickel oxide, dibasic ammonium phosphate, and water is made into a paste, paint or spray for coating the surface, which is then heated to reduce and fuse the bond. This temperature is much lower than the melting point of either the base metal or elemental nickel.—A. M. F.

Finishing Metal Surfaces for Aircraft Gas Turbines. W. B. Stephenson, jun. (*Products Finishing*, 1954, **18**, Aug., 24–29). In a general article, information is given on plating stainless steels with nickel, nickel–rhodium, and silver.—A. D. H.

The B.N.F. Jet-Test on Organic Bright Nickel Deposits. J. Edwards. (*Bull. Inst. Met. Finish.*, 1954, **4**, Spring issue, 33–46). The rate of penetration in the B.N.F. jet test has been shown to vary with the thickness of deposit. A calibration curve relating apparent and true thickness must therefore be employed. The jet test is to be considered primarily as an acceptance test of the 'limit' type.—A. G.

Loss of Aluminium from Galvanising Baths. N. B. Rutherford. (*Metal Treatment and Drop Forg.*, 1954, **21**, June, 261–267). Experiments are described which indicate that aluminium is lost from galvanizing baths by reaction with the flux, and because the coatings, dross, and ash all contain more aluminium than the bath. Means for reducing this loss, and the method of calculating additions of aluminium to compensate for it are discussed. (26 references).—P. M. C.

Industry Accepts Tin–Zinc as Steel Protective Coating. (*Tin*, 1954, June, 134–135). The advantages and applications of tin–zinc alloy plating for steel are briefly reviewed. The Tin Research Institute, which developed this plating alloy, recommends electroplating as the best coating method.

Tin–Nickel Alloy Coatings—Estimation of Thickness and Porosity. S. C. Britton and D. G. Michael. (*Bull. Inst. Met. Finish*, 1953, **3**, Autumn issue, 143–162). For non-ferrous base metals, solution in concentrated phosphoric acid or by anodic treatment with hydrochloric acid is suitable for determining thickness. Magnetic methods may be used for steel. Porosity may be assessed by exposure over dilute sulphur dioxide and treatment with ammonia.—A. G.

The Crystal Structure of Electrodeposited Tin Coatings on Iron Single Crystals. D. J. Evans. (*Bull. Inst. Met. Finish.*, 1953, **3**, Autumn issue, 173–180). Tin deposited electrolytically on iron single crystals has either a (100) or (110) plane parallel to the surface, both these planes being parallel to the corresponding ones in the iron.—A. G.

Aluminizing of Steel. A. N. Kapoor, A. B. Chatterjea, and B. R. Nijhawan. (*J. Sci. Indust. Res.*, 1954, **13B**, Apr., 286–291). A simple two-stage aluminizing process consists of initial heating in a halide bath followed by hot dipping; the flux contains cryolite, chlorides of zinc, sodium, potassium, barium, calcium, and ammonia, and aluminium fluoride. The adherence of the coating depends on mutual diffusion of iron and aluminium, and the various phases of the alloys are distinguished. The mechanical deformability of the coating depends on the thickness of the brittle alloy layer, which can be reduced by adding silicon to the bath. (16 references).

An Introduction to the Electrodeposition of Aluminium. A. W. Castle. (*Electroplating*, 1954, **7**, Aug., 291–305). Deposition of aluminium is possible from both fused salt and

organic electrolytes. Two examples of the latter are given in detail. No process is yet considered suitable for industrial mass production.—A. D. H.

The Dalic Plating Process. (*Indust. Finishing*, 1954, **6**, June, 836–838). A new plating development is described, by which *in situ* coatings can be applied to such parts as worn hydraulic rams, aircraft undercarriages, propeller blades, electrical contact surfaces, and portions of long tubes or rods. The surface is prepared normally, and a special organic compound of the metal is brushed on; plating is effected with the specially designed tampon. Among the metals which can be applied are cadmium, chromium, copper, iron, nickel, platinum, silver, tin, and zinc.—K. E. J.

Extend Applications of Nickel Immersion Plating. A. E. Durkin. (*Iron Age*, 1954, **174**, July 8, 91–94). The principle of the method of chemically depositing nickel (as opposed to electroplating) is given. The properties of the coating, applications, advantages, and disadvantages of the process are described.—D. L. C. P.

Plating Setup Recycles Propellers for Proper Balance. C. B. Conwell and C. J. Stansfield. (*Iron Age*, 1954, **173**, May 20, 133–135). The arrangements and operation of an automatic plant for zinc plating large hollow steel propeller blades is described. The operator can pre-select the operations and recycles each one shall undergo. With the special features, output is increased, and more consistent deposits are obtained. The plating is for protection, but is also applied so that the blades are perfectly balanced.—D. L. C. P.

Automatic Zinc Plating. C. E. Fisher and D. F. Zlatnik. (*Metal Progress*, 1954, **66**, Sept., 107–112: *Products Finishing*, 1954, **18**, Sept., 110–125). A description is given of an automatic plant for zinc plating steel cartridge cases at the Riverbank Ordnance Plant, California. The zinc plate is deposited electrolytically from an alkaline cyanide plating bath. The surface of the zinc coating is converted to zinc chromate by a second electrolytic process.—B. G. B.

Improvement of the Corrosion Resistance of Tinplate by a Chemical Treatment. S. C. Britton and R. M. Angles. (*J. Appl. Chem.*, 1954, **4**, July, 351–364). Tinplate immersed in 1% caustic soda, 0·3% sodium chromate solution at 90–95° C. for at least 3 sec. shows greatly increased resistance to corrosion and sulphur-staining. Ten minutes in a 1% chromic acid, 9% phosphoric acid solution at 90° C. provides even better protection.—J. O. L.

Boronizing, Siliconizing and Borosiliconizing of Steels by Electrolysis. P. Blum and J. L. Andrieux. (*Rev. Mét.*, 1954, **51**, Oct., 679–682). Previous work on the boronization and siliconization of iron has been extended to a number of alloy steels and the composition of the cemented layers has been studied by radiometallography. The borosiliconizing of iron is considered as a function of the boron/silicon ratio in the electrolytic bath and a possible mechanism of double cementation is suggested.—A. G.

Molybdenum Coatings Expand Uses of Metallizing. A. P. Shepard. (*Iron Age*, 1954, **174**, July 1, 105–107). Applications of sprayed molybdenum coatings are reviewed and specific examples given. Sprayed molybdenum coatings bond well to clean steel and other metals.—D. L. C. P.

Experiences with the Electrometallisor EM-6. A. M. Edelson. (*Schweisstechn.*, 1954, **8**, July-Aug., 90–92). The electrometallisor EM-6 is described. The spraying pistol contains two electrodes to form the arc; it is suitable for spraying with steel wire 1·5–2·5 mm. in dia. Data are given for spraying capacity in relation to feeding speed and wire diameter.—U. E.

The Role of Red Lead in the Protection of Iron and Steel. H. Masscille. (*Peintures—Pigments—Vernis*, 1954, **30**, Aug., 630–638; Sept., 731–738). A comprehensive account of the use of paints containing red lead to minimize the corrosion of iron and steel is given. Examples are given showing the efficacy of red lead paints in a variety of corroding conditions. The stability of paint films and the different types of red lead used in manufacture are considered. The fine dispersion of red lead in paint and specifications for the manufacture of lead paints are discussed.—B. G. B.

POWDER METALLURGY

Some Aspects of Powder Metallurgy. R. Girschig. (*Rev. Mét.*, 1954, **51**, Oct., 665–673). The structure of cast alloys is determined by the laws of solidification whilst for sintered alloys diffusion in the solid state is the governing factor. Theoretical consequences of this basic difference are discussed.

Studies in Reduction of Powdered Haematite: Part I—Batch Reduction. Part II—Continuous Reduction in a Rotary Kiln. R. M. Khandwala and G. S. Tendolkar. (*J. Sci. Indust. Res.*, 1954, **13B**, Aug., 561, 568–571). The production of pure iron powder by the reduction of high-grade hematite in hydrogen by a batch process has been investigated in detail. At an optimum temperature of about 650° C. and with particle size below 48 mesh, the reaction proceeds at a rate depending only on the supply of hydrogen. Similar considerations apply to reduction in a rotary kiln, but ultra-fine powders (— 200 mesh) are unsuitable owing to adhesion and the feed rate must be accurately adjusted to suit the kiln slope.—J. O. L.

Develop New Source for Electrolytic Iron Powder. R. N. Okuno and L. H. Mott. (*Iron Age*, 1954, **174**, Aug. 19, 132–133). The preparation and properties of iron powder from a new source, and its value for producing sintered metal parts are considered. The iron is a by-product from the processing of Japanese electrolytic sheet iron.—D. L. C. P.

Sheet Metals Can Be Made from Metal Powder. W. D. Jones. (Amer. Metal Powder Assoc.: *Machinist*, 1954, **98**, Aug. 21, 1465–1467). Continuous manufacture of sheets, rods, tubes, and extruded sections from powders extracted directly from ore eliminates steps in fabricating processes. Methods employed and advantages gained are described.—M. A. K.

Advance Compacting Press Design. (*Product Eng.*, 1954, **25**, Sept., 142–145). The Baldwin-Lima-Hamilton Corp. have built a press specially for compacting metal powders. A detailed description of it is given. Design features include four column construction to maintain exact die alignment, and independently floating die holder and core rod. The press stroke can be varied during a production run without stopping the press.—A. M. F.

PROPERTIES AND TESTS

Observations on the Elastic Range of Steels. R. de Strycker. (*Rev. Mét.*, 1954, **51**, Aug., 551–557). The deformation of basic mild steels close to the lower elastic limit has been studied. For a mild steel annealed and slowly cooled the extent of the elastic range varied directly with deformation speed and inversely with the time to produce measurable deformation, or the temperature at which slow cooling was stopped. An after-contraction of the specimens may be related to Cottrell's theory of atmospheres.—A. G.

Size Effect in the Tension Test of Mild Steel. C. W. Richards. (*Amer. Soc. Test. Mat. Preprint No.* 84, 1954). The author has developed a theory to explain the influence of specimen size on mechanical testing. Because of its statistical nature a large number of tests are required to check the theory. The present paper covers the first series of tests which were made in tension. In the tensile testing of mild steel the specimen size is one of the important variables.—B. G. B.

A New Triaxial Stress Testing Machine for Determining Plastic Stress-Strain Relations. H. A. B. Wiseman and J. Marin. (*Amer. Soc. Test. Mat. Preprint No.* 85, 1954). This new machine applies two equal compressive principal stresses with a third principal stress either in tension or compression. The mechanical properties of materials under various states of triaxial stresses can be obtained and triaxial stress–strain relationships can be determined.—B. G. B.

An Inexpensive Constant-Load Testing Machine. M. E. Clark and O. M. Sidebottom. (*Amer. Soc. Test. Mat. Preprint No.* 85A, 1954). The machine described is suitable for the application and maintenance of constant loads. It consists of a hydraulic jack, an accumulator for oil to gas coupling, and a reducing valve for regulating the gas pressure from a high pressure supply. Using commercial nitrogen cylinders, the machine has a capacity of 100,000 lb. Data obtained during the operation of the machine are given.—B. G. B.

Poisson Effect in the Charpy Test. C. E. Hartbower. (*Amer. Soc. Test. Mat. Preprint No.* 77, 1954). A linear relationship exists between the Poisson effect and the energy to fracture pearlitic steel bars in the Charpy test. This relationship obviates the measurement of lateral expansion or contraction in the Charpy test as the energy may be read directly from the calibrated testing machine.—B. G. B.

Effect of Specimen Size on Notched Bar Impact Properties of Quenched-and-Tempered Steels. H. Schwartzbart and J. P. Sheehan. (*Amer. Soc. Test. Mat Preprint No.* 79, 1954). The Charpy impact properties of six American steels (including

Cr–Ni, Cr, and Ni–Cr–Mo steels) were studied in the quenched and tempered condition. Three sizes of specimen geometrically similar with constant notch radius were used.—B. G. B.

Drop Weight Test Measures Notch Ductility. W. S. Pellini, G. A. Sandoz, and H. F. Bishop. (*Iron Age*, 1954, **174**, July 8, 100–103). The details and implications of a test developed at the U.S. Naval Research Laboratory to measure the notch ductility of nodular irons are given, and the value of the results is explained. The sharpest possible notch condition is introduced in the specimen by breaking, with a dropped weight, a brittle weld deposit on the specimen; the lowest temperature at which a specimen material does not fracture after a further slight bending is noted. It is assumed that above this temperature, brittle failure would not start in service, as the material has the ability to deform appreciably, even in the presence of a sharp crack.—D. L. C. P.

Cold Working of Metals. J. G. Wistreich. (*J. Iron Steel Inst.*, 1955, **180**, May, 51–59). [This issue].

Thoughts on the Vauthier Cold Working Capacity of Sheet Metal. P. Vauthier. (*Métaux—Corrosion—Indust.*, 1953, **28**, Nov., 437–459; 1954, **29**, Feb., 57–63; June, 242–258). The results of investigations of factors influencing the cold working capacity of steel sheet (including stainless steel) are given and discussed. A new standard test (P.V.I.) for this is described. Anisotropic properties of sheet metals and their effect on the stamping properties of sheet metals are discussed. The maximum amount of deformation which sheet metals can undergo is related to the P.V.I. test. The origin and effect of preferentially orientated structures on the shaping capacity are considered and the application of the P.V.I. test for studying internal stresses formed during the preparation of metal in sheet form is discussed.—B. G. B.

Introduction to the Study of the Cold Working Capacity of Sheet Metal. P. Vauthier. (*Métaux—Corrosion—Indust.*, 1954, **29**, Oct., 361–371). A review of factors influencing the cold working properties of sheet metal is presented. The influence of internal stresses, crystalline and polycrystalline plasticity, and of the Kuntze microfissures on cold working are discussed.—B. G. B.

The Kinematics of Plastic Flow—Some Observations on Models. W. Kossel. (*Z. Metallkunde*, 1954, **45**, Aug., 476–483). Stationary dislocations in crystals do not provide a sufficient theoretical explanation of the phenomena involved in plastic flow or slip, as the kinematics of dislocations postulate that the front of a moving dislocation differs from its back. The understanding of dislocations is greatly facilitated by the use of models. Bragg's soap bubble model is modified for the study of moving dislocations by cinematographic methods of recording. The author uses pictures exposed so long that the average travel of a bubble equals the sum of the diameters of two adjacent bubbles. These pictures and stationary images are then projected alternately. Even 20 pictures are sufficient to give a live impression of the phenomena involved in stress, compression, and shear in a field of soap bubbles. Pictures taken with long exposure demonstrate the nucleation and formation of slip bands and the combined effect of two slip bands. The formation of flow lines under tensile stress is also shown by the soap bubble model. One picture shows the formation of a slip band. The slip phenomena shown in the models is discussed with special reference to plastic flow in metals.—T. G.

Instrument for the Measurement of Static and Alternating Strain and Damping Capacity. W. Krägeloh. (*Z.V.d.I.*, 1954, **96**, Sept. 1, 864–866). The instrument, developed at Stuttgart University, is based on strain gauges and the carrier frequency technique; strains and loads are recorded, if need be as co-ordinates so that damping capacity may be caused from the hysteresis loop. Description of instrument design includes data on performance.—J. G. W.

The Determination of Stresses in Plane Circular Plates by the Photoelastic "Freezing" Method. A. Ferro. (*Ing. Mecc.*, 1954, **3**, Feb., 25–29). [In Italian]. A description is given of the application of the three-dimensional photoelastic 'freezing' method to the investigation of specific cases of flat circular plates submitted to a systematic distribution of stresses and to substantial strains. The results are compared with results calculated by Grashof's formula and, for the case of perforated plates, with Almen and Laslo's formulæ. (12 references).—M. D. J. B.

Transducers: The Electric Resistance Strain Gauge. (*Mech. World*, 1954, **134**, Sept., 390–393). The article deals with the application of electric resistance strain gauges as industrial transducers. Brief details are given of their use in stress measurement, weighing, power and pressure measurement, shut-off devices, and for determining vibration and impact effects.—D. H.

Brittle Failure of Steel Structures. M. E. Shank. (*Metal Progress*, 1954, **66**, Sept., 83–88; Oct., 120–126). A survey is made of some well-known cases of failures of steel plate by brittle cracking. Both welded and riveted methods of construction have failed from this cause and the structures include bridges, ships, pressure vessels and pipes. The influence of thermal and residual stresses and fabrication methods are discussed.—B. G. B.

The Necking of a Tension Specimen in Plane Plastic Flow. E. T. Onat and W. Prager. (*J. Appl. Phys.*, 1954, **25**, Apr., 491–493). A linearized version of the equations of plasticity is used in the discussion of the symmetrical necking of a tension specimen in plane plastic flow. The material is treated as perfectly plastic, and elastic strains are neglected.—J. O. L.

The Practical Testing of the Cohesive Strength and Weldability of Steels. W. A. Felix. (*Sulzer Tech. Rev.*, 1954, (1), 33–43). The mechanical properties which determine the suitability of a steel for use in highly stressed welded structures are discussed with particular reference to the tendency to brittle fracture and the sensitivity to ageing. The best known testing techniques and the methods adopted by Sulzer Brothers for assessing the properties of such steels are reviewed.—L. E. W.

New Principles for the Calculation of Welded Joints. C. G. J. Vreedenburgh. (*Welding J.*, 1954, **33**, Aug., 743–751). A method for calculating the strength of welded joints is explained. In dynamically loaded structures a symmetrical surface of revolution has been adopted as the shape of the critical surface of allowable effective stresses. This effective stress is obtained by multiplying the numerically greatest value of the oscillating stresses by a coefficient which is coherent with the fatigue diagram of the material and the type of weld.—R. A. R.

Heat-Treatment of Welded Structures for Relief of Residual Stresses with Particular Reference to Type 347 Stainless Steel Weldments. W. L. Fleischmann. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 645–648). Welded ring samples of an austenitic stainless steel (0·08% C, 17–19% Cr, 9–13% Ni, 1% Nb) were given a number of thermal treatments to determine whether they relieved thermal stresses. Temperatures of 1650° F. and above caused complete relaxation. Experiments on twisted wire of the same composition showed that relaxation occurred at temperatures up to 950° F. A treatment at 1100° F. produced some untwisting and established a pattern of residual stresses that did not cause any further movement when the wire was cycled between room temperature and 850° F.—D. H.

The Danger of Brittle Fracture in Welded Structures. E. Uhlir. (*Schweisstechn.*, 1954, **8**, June, 61–64; July-Aug., 77–79). The effect of residual stresses on the tendency to brittle fracture in welded structures is discussed and stress relief treatments are described. Experiments were carried out to determine the effect of sheet thickness and composition on the temperature distribution and weld stresses. An increase in stresses occurred with increase in sheet thickness; this was greatly influenced by sheet composition and electrode diameter. Methods of testing welds are briefly reviewed.—U. E.

Combined Research by Institut de Recherches de la Sidérurgie and Institut de Soudure on the Weldability of Steel. (*Soudure Techn. Connexes*, 1953, **7**, Mar.-Apr., 67–85).

I—Programme and Distribution of the Work. G. Delbart and A. Leroy. (67–69). The joint research programme is outlined.

II—Improvements to the Kinzel Test. (Notch Bend Test). J. P. Videau and R. Quigna. (69–74). The **V**-notch Kinzel bend test is studied on specimens with and without welds. Reproducible specimens are produced by an automatic electric welding method which is described. Tests are made on samples at temperatures between − 40° and + 20° C., and the transverse contraction is plotted against temperature, the former being measured by a special device.

III—Comments on the Comparison and Significance of the Tests. H. Granjon and J. P. Videau. (75–82). Various tests are compared, including a resilience test, and the Dutilleul, Kommerell, and Kinzel tests. Results of the Kinzel test on eleven different specimens at − 10° C. are

compared. Certain inconsistencies are discussed, and it is concluded that the decrease in transverse contraction follows, essentially, the state of strain in the sample.—T. E. D.

Bend Testing Machine for Welds. (*Schweissen u. Schneiden*, 1954, **6**, July, 310–311). A modification of the usual bend testing machine is described. The two large rolls are milled and their rotation is controlled by two adjusting screws; this ensures that the deformation takes place at the weld and prevents an additional tensile stress being set up in the test piece.—U. E.

Effects of Temperature on Weld Metal Properties. J. Heuschkel. (*Welding J.*, 1954, **33**, Aug., 388-s–397-s). Tensile properties of covered electrode medium and high-nitrogen weld metal in uniformly loaded specimens have been determined over the range from − 200° to + 1400° F. in the as-deposited and annealed conditions. The presence of more nitrogen effectively increases the yield point and nominal ultimate tensile stresses but reduces the true stress at fracture, the ductility values, and the work-absorbing capacity. It is also responsible for the occurrence of gas voids, but nitrogen contents as high as 0·020% are not detrimental to the ordinary tensile properties.—U. E.

A New Method for the Quality Control of the Spot-Welding of Lightly Alloyed, Semi-Hard Steels. P. Joumat. (*Cien. Tecn. Solda.*, 1954, **18**, May-June). [In Spanish]. This test was developed because of welding difficulties in the construction of railway carriage frameworks in a manganese steel (C 0·16%, Mn 1·25%) containing a small amount of chromium. A simple torsion-fracture test on 55 mm. square, spot-welded specimen plates is described. The appearance of the fracture gives a direct measure of the quality of the weld.—P. S.

Advances in the Determination of Residual Stresses by X-Ray Methods. A. Priegue Guerra. (*Cien. Tecn. Solda.*, 1954, **19**, July-Aug.). [In Spanish]. The direct evaluation of X-ray diffraction patterns with a Geiger-Muller counter is described. The greater accuracy of this method compared with photographic recording is illustrated. Specimens of a steel were given a permanent set of 2% and the residual stresses measured. These specimens, originally 5·7 mm. thick, were thinned very carefully and the residual stresses redetermined at intervals. The stresses were virtually eliminated when the thickness had been reduced by 1·5 mm.—P. S.

Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 158, 1953). This Symposium was held at the 56th Annual Meeting of the A.S.T.M. at Atlantic City on June 28–30, 1953. The following papers were presented:

Brittle Failures in Ships and Other Steel Structures. K. K. Cowart. (3–10). An introductory account is given of some of the more important failures of steel structures due to brittle fracture. Examples of brittle fracture in oil tankers are cited.—B. G. B.

Analysis of Brittle Behaviour in Ship Plates. M. L. Williams. (11–44). An analysis of data obtained from investigations of structural failure in nearly 100 ships is presented. Samples were taken from fractured areas for testing. In every fracture examined the starting point could be traced to a point of stress concentration. The **V**-notch Charpy tests showed that plates in which fractures originated were generally more notch sensitive than plates which did not contain the source of fracture.—B. G. B.

A Critical Survey of Brittle Failure in Carbon Plate Steel Structures Other than Ships. M. E. Shank. (45–110). Brittle failure in ships and other structures is the same phenomenon. The effect of variation in the composition of the steel is important. Increase in the ferritic grain size, carbon and phosphorus contents, and plate thickness increase the susceptibility to brittle fracture. Increase in the manganese content and normalizing will lower the susceptibility. There is no evidence to show that the percentage incidence of brittle failure has either increased or decreased with the advent of welding. (129 references).

The Interest of the Army in Brittle Failures. T. T. Paul. (111–115). A short account of the importance of minimizing brittle fracture of army equipment is presented.—B. G. B.

Theory of Brittle Fracture and Criteria for Behavior at Low Temperatures. E. R. Parker. (116–132). Steel can fail either by shear or by cleavage. Shear failures follow slip planes in the ferrite crystals and, on a macroscopic scale, occur on planes of maximum shear stress. Cleavage failures follow cubic planes within individual crystals and planes of maximum tensile stress on a macro-scale. Standard unnotched tensile specimens fail by shear at normal temperatures but by cleavage, without measurable elongation, at liquid nitrogen temperature. The ratio of maximum shear to maximum tensile stress is reduced by notches so that brittle fractures can occur at room temperatures.

Brittle Fracture. S. L. Hoyt. (133–146). Notch-bar testing and its use in judging steels for engineering applications which involve the risk of brittle fracture in service are reviewed. The author stresses the need to reproduce in the laboratory the conditions which led to failure in practice.—B. G. B.

Metallurgical Aspects of Low-Temperature Behavior in Ferrous Materials. C. H. Lorig. (147–163). The behaviour of brittle steels at low temperatures is shown to be closely related to composition, the alloying elements, microstructure and heat-treatment. Close control of the composition, deoxidation, microstructure, and of grain size during manufacture and improved techniques of manufacture and fabrication is considered to be a practical way of reducing brittle fracture in brittle-sensitive steels.—B. G. B.

Fundamentals of Fractures in Metals. M. Gensamer. (164–175). The theoretical principle governing the fracture of metals is considered and the influence of temperature on the brittleness of steels is discussed. Methods of measuring the brittleness of steels are reviewed.—B. G. B.

The Effect of Size upon Fracturing. G. R. Irwin. (176–194). The influence of specimen size on the fracture of steel is considered. It is possible to correlate the results obtained for specimens of varying size. A statistical approach is made to the theory of fracture strength based on flow distribution probabilities.—B. G. B.

Brittleness, Triaxiality and Localization. W. P. Roop. (195–202). The numerical evaluation of triaxiality in round bars is discussed and differences between the axial component of stress and maximum load for notched and necked bars are considered. Stresses in notched plates in tension are also dealt with.—B. G. B.

Effect of Metallurgical Structures on the Impact Properties of Steels. J. A. Rinebolt. (203–215). A comparison of the Charpy **V**-notch properties of steels having a spheroidal martensite, spheroidal pearlite, and a normalized structure has been made. Five series of steels were used in which the carbon, manganese, silicon, phosphorus, and nickel contents were varied. The transition temperature of all three structures was raised by addition of carbon, phosphorus and silicon, and lowered by manganese and nickel.

Evaluation of the Significance of Charpy Tests. W. S. Pellini. (216–261). A comprehensive analysis of the problem of brittle fracture is made. The critical fracture and ductility transformation temperatures for steels may be determined by the use of conventional notch-bend specimens. Impact and explosion loading tests of sharply notched specimens of sufficient size to be considered prototypes of actual structural parts result in ductility and fracture behaviour similar to that observed in service. The significance of Charpy **V** and keyhole tests in service performance is related to the transition features of the energy transition curves.—B. G. B.

Significance of V-Notch Impact Test in Evaluation of Armour Plate. A. Hurlick. (262–274). Details are given of the use of the Charpy **V**-notch test as used by the U.S. Ordnance Corps for evaluating the resistance of armour to cracking or shattering under shock impact.—B. G. B.

Notch-Bend Tests for Evaluating the Properties of Weldments. R. D. Stout. (275–285). An examination is made of results obtained from a number of different notch bend tests on welded specimens. The effect of welding on the properties of steel is discussed.—B. G. B.

Reproducibility of Keyhole Charpy and Tear-Test Data on Laboratory Heats of Semikilled Steel. R. H. Frazier, J. W. Spretnak, and F. W. Bougler. (286–307). Two types of semi-killed steel were investigated. The probability of brittle fracture was not the same for the two types of steel in tests at their transition temperature. The difference was small in the Charpy tests but significant in tear tests. It is concluded that notched-bar transition temperature should be defined on the basis of a fixed probability of brittle fracture. This practice uses the data more efficiently and is more discriminating.—B. G. B.

Effect of Specimen Preparation on Notch-Toughness Behaviour of Keyhole Charpy Specimens in Transition Temperature Zone. R. W. Vanderbeck, R. W. Lindsay, H. D. Wilde, W. T. Lankford, and S. C. Snyder. (308–325). A number of Charpy impact tests have been conducted within the transition range of several steels using different methods of specimen preparation. Only the usual amount of precaution need be taken to obtain realistic and satisfactory estimates of the transition temperature and of the transition temperature range. Particular care in preparing the notch did not reduce the width of the transition range. The characteristic scattering in this range is probably due to variations within the steel itself rather than to specimen preparation.—B. G. B.

Effect of Boron on Impact Properties of Quenched and Tempered Steels. H. S. Schwartzbart and J. P. Sheehan. (332-344). The effect of boron was to increase the Jominy hardenability to a larger extent. Boron has little effect on the variation of hardness and maximum energy absorption with tempering temperature but has a marked effect on the variation of transition temperature with tempering temperature.—B. G. B.

The Notched-Bar Impact Properties of Tempered Martensite in Medium-Carbon, Medium-Alloy Grades of Steel. M. Baeyertz, W. F. Craig, jun., and J. P. Sheehan. (345–364). Several steels of this type were studied. Particular interest was paid to the influence of the molybdenum/phosphorus ratio on steel brittleness. Variation in **V**-notch Charpy brittleness from heat to heat of the same grade of steel is much less if this ratio is kept at 5 or higher when tests are to be conducted on specimens quenched in water after tempering. If reduction of the susceptibility to temper brittleness is also desired the ratio of molybdenum to phosphorus needs to be higher.—B. G. B.

Notch Sensitivity of Steels. E. J. Ripling. (365–373). The proportion of room-temperature notch brittleness of a high-strength steel which can be attributed to transition temperature behaviours was determined. An extrapolation of the supertransition temperature portion of the ductility/testing-temperature curve to room temperature indicated that practically all the embrittlement resulted from a shift in the transition temperature.—B. G. B.

Effect of Carbon and Nitrogen on the Tensile Deformation of High-Purity Iron at 81° F. (27° C.) and at − 321° F. (− 196° C.). L. D. Hall. (374–381). A study has been made of the tensile deformation of fine-grained high-purity iron at these two temperatures. The effect of small additions of carbon and nitrogen, respectively, to the parent metal was investigated. It was found that carbon can give considerable ductility to iron at the temperature of liquid nitrogen (− 196° C.). Nitrogen, however, has an embrittling effect at both temperatures.—B. G. B.

Tension Impact Strength and Strain Distribution at Room and Sub-Zero Temperatures of Stainless and Other Steels. C. R. Mayne, V. N. Krivobok, and C. W. Muhlenbruch. (382–404). Impact tests on pearlitic, acicular, and austenitic cast irons indicate a decrease of 10 to 20% in numerical values for pearlitic irons cooled to − 100° F. (50% when cooled to − 300° F.). Acicular Ni–Mo irons behave in a similar manner although actual toughness at − 300° F. is approximately the same with pearlitic irons at room temperature. Austenite irons possess a higher order of toughness at room temperature and retain a greater percentage of it than pearlitic irons do at temperatures down to − 300° C. The best material tested was a modified Ni-Resist iron containing spheroidal graphite. This could not be broken within the capacity of the Izod machine even when subjected to four successive blows at − 300° F.

Low-Temperature Toughness of Flake and Spheroidal Graphite Cast Iron. J. S. Vanick. (405–414). Impact tests carried out on pearlitic, acicular, and austenitic cast irons indicated a decrease of about 10 to 20% in tensile strength for pearlitic irons cooled to − 100° F. and 50% at − 300° F. Acicular Ni–Mo irons follow a similar trend on cooling; their toughness at − 300° F. is the same as that of pearlitic irons at room temperature. The austenitic irons possess a higher order of toughness at room temperatures and retain a greater percentage of it than the pearlitic irons do at temperatures down to − 300° F.—B. G. B.

Ductile and Brittle Failure in Ferritic Nodular Irons (Nickel–Magnesium Type). G. N. J. Gilbert. (415–431). At room temperature, annealed ferritic nodular cast iron can fail in impact in a ductile manner with a relatively high impact value, or in a brittle manner with a relatively low impact value depending on the composition and treatment. Silicon and phosphorus raise the temperature of transition from brittle to ductile failure. The unnotched impact test for the most part measures the energy required to initiate a crack; the notched-bar impact test measures the energy required to propagate a crack.—B. G. B.

Low Temperature Properties of Cast Irons. G. N. J. Gilbert. (432–455). The impact and tensile properties of flake graphite, pearlitic, acicular, martensitic, and austenitic cast irons at temperatures down to about − 180° F. were studied. The mechanical properties of acicular and austenitic materials are complicated because of the austenite to martensite transformation which occurs at low temperatures. In acicular materials the change occurs between − 54° and − 83° F., while in austenitic materials it varies widely with chemical composition.—B. G. B.

The Impact Properties of Ferritic Ductile Iron. R. W. Kraft. (456–474). A series of impact tests on ductile ferritic irons of various compositions and structures using a modified A.S.T.M. **Y** specimen has been carried out. No sharp transition temperature was detected. As the temperature is lowered down to − 100° F., or the silicon or phosphorus content raised, the impact strength falls off relatively slowly with a gradual transition from ductile to brittle fracture. The maximum silicon content permitting a ductile fracture in a low phosphorus iron at room temperature is 2·4%. Nickel has no apparent effect on impact strength.—B. G. B.

A Failure Criterion for Multi-Axial Fatigue Stresses. F. B. Stulen and H. N. Cummings. (*Amer. Soc. Test. Mat. Preprint No.* 76, 1954). A theory is developed for predicting fatigue failure in polycrystalline metals subjected to any combination of steady and vibratory multi-axial stresses. Data plotted to produce 270 stress/cycles curves for ductile and brittle metals were in agreement with the theory.—B. G. B.

An Appraisal of the Prot Method of Fatigue Testing. H. T. Corten, T. Dimoff, and T. J. Dolan. (*Amer. Soc. Test. Mat. Preprint No.* 69, 1954). The Prot method of fatigue testing, using the increasing load technique, has been studied by comparing the results obtained with ingot iron, a nickel steel, a boron steel, and an aluminium alloy with conventional fatigue data. Notched and unnotched specimens were used. This method is suitable for the rapid estimation of the endurance limit of the steels.—B. G. B.

A Concept of Fatigue Damage. S. M. Marco and W. L. Starkey. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 627–632). The effects of cumulative fatigue damage on endurance life were studied. Stepped stress sequences were applied to rotating-cantilever-beam specimens. Typical curves of fatigue damage in relation to number of cycles were deduced.—D. H.

Fatigue Tests on Rolled Alloy Steels made in Electric and Open-Hearth Furnaces. P. H. Frith. (*J. Iron Steel Inst.*, 1955, **180**, May, 26–33). [This issue].

The Influence of Surface Rolling on the Fatigue Properties of Flake Graphite and Nodular Graphite Cast Irons. G. N. J. Gilbert and K. B. Palmer. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1954, **5**, Oct., 447–464). The effect of surface rolling on the fatigue strength of 45° **V**-notch specimens has been investigated. Increases in fatigue limit of 20% in a pearlitic flake graphite cast iron and over 190% in a ferritic nodular iron were obtained. Surface rolling also results in an increase in the fatigue life at stresses above the fatigue limit.—B. G. B.

Softening of Certain Cold-Worked Metals under the Action of Fatigue Loads. N. H. Polakowski and A. Palchoudhuri. (*Amer. Soc. Test. Mat. Preprint No.* 74, 1954). A non-ageing titanium-killed steel was cold drawn 20 to 40% to 0·2 in. dia. and subjected to alternating tension–compression fatigue stressing at frequencies from 5500 to 9500 cycles/min. Compression tests and Vickers hardness tests showed pronounced softening. The results are discussed in the light of previous work on the Bauschinger effect and an interpretation of the present findings is offered on a pure stress-strain basis. (22 references).—B. G. B.

A Simplified Statistical Procedure for Obtaining Design-Level Fatigue Curves. E. H. Schuette. (*Amer. Soc. Test. Mat.*

Preprint No. 75, 1954). The author suggests a procedure which will provide stress curves for designers with only a fraction of the testing time required for obtaining complete statistical data and without the use of complex mathematics. B. G. B.

Effect of Annealing Condition on Hardness and Structure of High Carbon Steel Strips. I. Y. Fukao and M. Mori. (*Tetsu to Hagane*, 1954, **40**, July, 675–680). [In Japanese]. Studies were made on strip containing 0·47–1·38% C. A relationship was obtained between hardness and structure, the hardness being lowest for the spheroidized structure. In hyper-eutectoid steels, the temperature to develop the minimum hardness rose as carbon content increased, and was independent of the holding time. In eutectoid and hypo-eutectoid steels, it fell as the holding time increased, and the hardness value also fell.—K. E. J.

Micro-Indentation Hardness. P. Grodzinski. (*Metallurgia*, 1954, **50**, Sept., 125–131). A survey of the use of this method of hardness measurement is made. The results obtained for a variety of measurements of plastic hardness, elastic hardness, and the variation in hardness across a fracture are described.—B. G. B.

The Strain-Ageing of Pure Iron. Ageing of Pure Iron after Temper-Rolling and Tensile Straining. B. Jones and R. A. Owen-Barnett. (*J. Iron Steel Inst.*, 1955, **180**, May, 20–23). [This issue].

Effect of Composition on Transverse Properties of Slack-Quenched Steel. J. Vajda and P. E. Busby. (*Trans. Amer. Soc. Met.*, 1954, **47**, Preprint No. 24). Ten different compositions were selected to determine the effect of boron, rare-earth oxides, silicon, nickel, and carbon on hardenability in heavy sections and on the mechanical properties of tempered slack-quenched (quenching to a predetermined temperature substantially above atmospheric temperature) structures. The effectiveness of ferroboron and Grainal No. 79 is compared, and the applicability of the end-quench method to heavy sections is discussed.—A. G.

Hardenability of Carbon Tool Steel. N. J. Culp. (*Trans. Amer. Soc. Met.*, 1954, **47**, Preprint No. 15). A series of hardness-penetration curves is presented, which enables the depth of hardening in a shallow-hardening tool steel to be expressed in terms of a fundamental parameter. The parameter chosen is the rate of cooling in degrees Fahrenheit per second at 1300° F. at which the steel attains the critical hardness associated with the 50/50 martensite–pearlite structure. Experimental data indicate that the curves obtained are sufficiently accurate for practical applications.

Calculation of Hardenability in High Carbon Alloy Steels. C. F. Jatczak and R. W. Devine, jun. (*Trans. Amer. Soc. Met.*, 1954, **47**, Preprint No. 14). The effects of manganese, silicon, chromium, nickel, and molybdenum, singly and in combination, on the hardenability of 1·0% carbon steels were studied by the end-quench test at quench temperatures between 800° and 855° C. An empirical procedure for calculating hardenability is proposed; it has an accuracy of ±10% for normalized steels and of ± 15% for annealed steels.—A. G.

New Method for Detecting Temper Brittleness in Steels. B. Jaoul and P. Lacombe. (*Compt. Rend.*, 1954, **238**, Feb. 15, 817–819). A method of surface activation in which radioactive elements are incorporated in the etching medium has been applied to the study of temper brittleness of steels. By measuring the variation of activity from the surface inwards, the extent of an attack, not detectable by the optical microscope could be determined.—A. G.

Tests of Electric Flash Butt-Welded Rails. R. E. Cramer and R. S. Jensen. (*Illinois Univ. Eng. Exper. Sta., Reprint Series No.* 53, 1954, **59**, May, 30–40). Results of rolling-load, Brinell hardness, and bend tests are given. Final conclusions are not drawn yet but it appears that flash butt welds are satisfactory either as welded or when normalized.—R. P.

Investigation of Failures in Control-Cooled Railroad Rails. R. E. Cramer. (*Illinois Univ. Eng. Exper. Sta., Reprint Series No.* 53, 1945, **59**, May, 3–6). Failures in control-cooled railroad rails are attributed to transverse fissures from shatter cracks, from hot torn steel, shelling, engine burn fracture, and transverse fissure from inclusions.—R. P.

Twelfth Progress Report of the Rolling-Load Tests of Joint Bars. R. S. Jensen. (*Illinois Univ. Eng. Exper. Sta., Reprint Series No.* 53, 1954, **59**, May, 7–21). The results of rolling-load tests and of hardness tests on joint bars are described. Some bars which failed in service showed low hardness and low physical properties.—R. P.

Twelfth Progress Report on Shelly Rail Studies at the University of Illinois. R. E. Cramer. (*Illinois Univ. Eng. Exper. Sta., Reprint Series No.* 53, 1954, **59**, May, 21–29). Tests carried out led to the following conclusions: Stress-relieving during rolling-load tests at 800° and 1000° F. does not increase the life of rails appreciably. Flame-hardened rails gave results about 50% above standard carbon steel rails. The data for high-silicon steels were about twice as high as those for carbon steel rails. The cause of shelling is attributed to excessive wheel loads for the small contact area.—R. P.

Soft Magnetic Cores from Fe–Si–Al Powders, Also Called Alsifiers. H. Rutkowska and B. Winsch. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6**, (3), 149–156). [In Polish]. The influence of chemical composition, particle size, annealing conditions and the technology of production on the magnetic properties of cores made of Fe–Si–Al powders was investigated. It was found for alloys containing 5–9% Al and 7–10% Si, that: (*a*) For low aluminium (5% Al) alloys the magnetic permeability rapidly decreases and the losses increase with an increase of silicon content; (*b*) in alloys with 6–7·5% Al the permeability and losses due to eddy current only change a little with increasing silicon and the changes in hysteresis loss are irregular.—V. G.

Magnetic Properties of Cast Steel. F. Zedník. (*Slévárenství*, 1954, **2**, (7), 193–200; (8), 231–236). [In Czech]. A survey and analysis of the data on the effect of chromium, manganese, molybdenum, carbon, and aluminium on the magnetic induction of ferritic and pearlitic steels indicates that the total alloy content, expressed in atomic per cent., is an unreliable guide to magnetic behaviour, particularly in weak magnetizing fields. The magnetic induction and the mechanical properties of several alloy steels, some deoxidized with aluminium, are given over the range 25–200° C.—P. F.

Effect of Elastic Strain on the Electrical Resistance of Metals. G. C. Kuczynski. (*Phys. Rev.*, 1954, **94**, Apr. 1, 61–64). For most metals, including iron, the free electron theory confirms the experimentally determined strain coefficients of electrical resistivity, which are quoted.—J. O. L.

Testing Materials by Ultrasonic Methods. J. Ors Martinez. (*Inst. Hierro Acero*, 1954, **7**, Apr.-June, 174–187). [In Spanish]. The elastic constants and related equations for the velocity of propagation of waves in an isotropic medium are derived. Their measurement is described and diffraction phenomena are discussed. (75 references).—P. S.

Some Applications of the Ultrasonic Testing of Rails. L. Beaujard and V. Husarek. (*Rev. Mét.*, 1954, **51**, Aug., 558–568). The methods developed by IRSID for testing rail heads are outlined and a number of experiments are reviewed in which ultrasonic techniques have revealed the presence of defects due to fatigue or other cause.—A. G.

Ultrasonics in Maintenance Planning and Product Quality Control. R. L. Rectenwald. (*Iron Steel Eng.*, 1954, **31**, Sept., 77–85). The author describes an ultrasonic thickness measurer and a flaw detector. Information is given on piezoelectric transducers and their mode of operation. The resonance and echo systems are discussed and their characteristics and applications are described.—M. D. J. B.

Flaw Detection in Metal Tubes by Means of an Induced Electric Current. G. Gauthier. (*Rev. Mét.*, 1954, **51**, Aug., 537–540). In general, the use of induced currents yields diagrams whose variations correspond closely to the flaw dimensions measured by micrographic means. Examples of anomalies in such diagrams are given and an attempt is made to explain them.—A. G.

Theoretical and Experimental Principles of the Electromagnetic Sorting of Semi-Finished Steel and Steel Parts. I. The Magnetoinductive Method, Considering Only the Fundamental Waves. F. Förster. (*Z. Metallkunde*, 1954, **45**, Apr., 206–211). The author first gives in tabular form the chief points of the three commonest electromagnetic sorting methods. He then outlines the theoretical principles of the "Magnatest Q" apparatus, with reference to the fundamental wave effect. From these it is possible to select the optimum frequency range when sorting by differences in conductivity, permeability, and diameter.—L. D. H.

Theoretical and Experimental Principles of Electromagnetic Sorting of Steel Parts. IV. The Residual Field Method. F. Förster. (*Z. Metallkunde*, 1954, **45**, Apr., 233–238). The quantitative relationship between residual field and coercive strength is established, and the industrial application to the fully automatic sorting of steel parts is described on the basis of hardness and strength, as these properties are related to coercive strength.—L. D. H.

Short-Time Tension and Creep-Rupture Properties of Hardened 1040, 4340, and Ni–Cr–Mo–V Steels up to 1000° F. G. V. Smith and W. B. Seens. (*Amer. Soc. Test. Mat. Preprint No.* 78, 1954). Short-time tensile properties at 80°, 500°, 700°, 850°, and 1000° F. and creep rupture properties at 850° and 1000° F. are reported for these American alloy steels heat-treated to a tensile strength of 150,000 lb./sq. in. at room temperature.—B. G. B.

Notch-Bar Tests of High-Strength Steel. R. Raring and J. Rinebolt. (*Amer. Soc. Test. Mat. Preprint No.* 80, 1954). Charpy V-notch specimens of a Cr–Ni–Mo steel heat-treated to give a tensile strength of 210,000 and 230,000 lb./sq. in. were tested in the temperature range − 320 to + 320° F. by the conventional impact test and by slow bending. Energy absorption calculated from load-deflection data of the slow test was much less than that calculated from the impact test. The mechanism of crack formation and propagation in such specimens of high-strength steels is shown to be different from that of pearlitic steels or softer quenched and tempered steels.—B. G. B.

The Strength of Carbon Steels for Elevated-Temperature Applications. R. F. Miller. (*Amer. Soc. Test. Mat. Preprint No.* 81, 1954). Elevated temperature tension, creep, and rupture tests have been carried out on silicon steel plate and seamless carbon steel tubes as used in boiler construction. The plate was tested after stress relieving and the pipe in the as-rolled condition. The grain coarsening characteristics were determined.—B. G. B.

The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures. L. F. Coffin, jun. (*Amer. Soc. Test. Mat. Preprint No.* 100a, 1954). The localization of cyclic strain caused by thermal fluctuation is principally responsible for thermal stress fatigue failures in structures fabricated from austenitic stainless steels. Mechanisms for strain localization are discussed and the results of experiments on specimens designed to demonstrate the effect are given.—B. G. B.

Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys. J. Miller. (*Amer. Soc. Test. Mat. Preprint No.* 100*b*, 1954). Cyclic temperature rupture tests have been conducted on four different high temperature alloys. The results are compared with the calculated lives to rupture using constant temperature rupture data and integrating the life expenditure over a complete temperature cycle. The calculated and actual test values correlate very well, although in general the actual values are somewhat lower than the calculated values.—B. G. B.

Constant and Cyclic-Load Creep Tests of Several Materials. W. F. Simmons and H. C. Cross. (*Amer. Soc. Test. Mat. Preprint No.* 100*d*, 1954). Constant load and cyclic load creep tests have been made on sheet specimens of a Cr–Ni–Mo steel at 800° F. and a stainless steel at 1500° F. Application of the load by cycling did not increase the rate of creep of the materials tested and there was no evidence of recovery taking place during the low-load part of the cycle. The data obtained, though incomplete, indicate that it is probably safe to design for cyclic load conditions using data from constant-load tests. B. G. B.

The Properties of Aircraft Steels When Heated to Temperatures up to about 400 deg. C. G. Meikle. (*Brit. Steelmaker*, 1954, **20**, Oct., 390–396). The author discusses the strength of materials used at elevated temperatures in high-speed aircraft, and considers the possible use of steel. He reviews available information on the strength of steel up to temperatures of about 350° C., and supplements this with the results of tests carried out at the Royal Aircraft Establishment, Farnborough.—G. F.

Future Trends in Aircraft Gas Turbine Engine Materials. E. R. Gadd. (*Brit. Steelmaker*, 1954, **20**, Oct., 383–397). The author surveys materials now used in gas turbine engines and draws attention to the competition which steel can expect to meet from some of the latest titanium-base alloys. The prospective development of materials for engine casings, shafts, and bearings is also discussed.—G. F.

How Radiation Affects Structural Materials. C. R. Sutton and D. O. Leeser. (*Iron Age*, 1954, **174**, Aug. 19, 128–131; Aug. 26, 97–100). Experiments on the effect of radiation on the mechanical and physical properties of plain and alloy steels, and other materials for nuclear reactors are described and the results summarized. Tests were made on specimens submitted to a range of irradiation and temperature exposures. In general, materials have higher yield strength and hardness, lower elongation, and somewhat higher ductile-brittle transition temperatures. Hardness is reduced by annealing when exposure temperatures are higher.—D. L. C. P.

Jet Engine Metallurgy. R. B. Johnson, jun. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 45–54). The author indicates the operating temperatures in the various sections of a typical aircraft gas turbine engine, and discusses some of the problems encountered with regard to the metals and alloys used for the different components. The experience of the General Electric Co. in the production of these engines is outlined.—G. F.

Materials for Gas Turbines. H. Sutton. (*J. Inst. Prod. Eng.*, 1954, **33**, Aug., 449–453, 448). An account is presented of the development and properties of high temperature alloys for the rotor blades, rotor disc, nozzle guide vanes, stationary blades, and the combustion chamber of gas turbines. Future trends in the development of new materials are considered.

Statistical Evaluation of the Creep Rupture Properties of Four Heat-Resistant Alloys in Sheet Form. A. I. Rush and J. W. Freeman. (*Amer. Soc. Test. Mat. Preprint No.* 82, 1954) Stress rupture, total deformation, and tensile test data have been obtained from specimens of two 18/8 steels and two non-ferrous alloys. All the data were examined statistically to establish average values for each alloy and the standard deviations where sufficient data were available.—B. G. B.

Thermal-Shocking Austenitic Stainless Steels with Molten Metal. R. A. Tidball and M. M. Shrut. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 639–643). Specimens of austenitic steel pipe (0·08% C, 17–19% Cr, 9–13% Ni, 1% Nb) and pipe welds were subjected to thermal shocks by quenching the inner surface with cool sodium–potassium alloy. The equipment used and a method of measuring the transient, fluid, and wall temperatures are described. Temperature changes encountered during tests and resulting stresses are shown. The effects of 2500 transient thermal cycles on one specimen are discussed.—D. H.

Vanadium and Molybdenum in Medium Manganese Cast Steel. C. C. Spencer. (*Amer. Foundryman*, 1954, **26**, July, 45–47). Results of tests on casts of 0·25%-C 1·25%-Mn steels are briefly reported. In the quenched and tempered condition a steel with 0·1% V has mechanical properties equal to those of one containing 0·3% Mo.—B. C. W.

Rare Earths in Stainless Steels. H. O. Beaver. (*Metal Progress*, 1954, **66**, Oct., 115–119). The use of rare earth additions to stainless steels is considered. Addition to high-alloy austenitic stainless steels which are inherently hot short can transform them into ductile alloys. The hot workability of inherently ductile austenitic stainless steels can be improved. Steels with rare earth additions are not detrimentally affected.

High-Tensile Steels. J. Apraiz. (*Bol. Mind. Ind.*, 1954, **33**, May, 269–277). [In Spanish]. The compositions and properties of Echevarria steels are given.—R. S.

Test New Alloy Steel for Pressure Vessels. (*Iron Age*, 1954, **174**, July 22, 120). A brief report is given of burst and drop weight tests on large alloy steel pressure vessels made of Carilloy T-1 steel (C 0·15%, Mn 0·92%, P 0·014%, S 0·020%, Si 0·26%, Ni 0·88%, Cr 0·50%, Mo 0·46%, V 0·06%, Cu 0·32%, B 0·0031%). This steel was heat-treated and withstood very heavy impacts when cooled to − 45° F. The vessel eventually broke with a ductile fracture.—D. L. C. P.

Hot Forging and Rolling of Iron Castings. C. R. Austin. (*Foundry*, 1954, **82**, July, 86–89, 244). Data on the effects of forging and rolling on cast irons are presented and discussed. Hot-forging of flake graphite iron at 900° C. or 980° C. to 50% reduction, considerably raised the tensile strength, elastic modulus, limit of proportionality, and yield strength of the normalized bars without increasing the hardness. Mottled irons containing free carbide were forged and then rolled at 1040° C. and the tensile strength and elastic modulus of the normalized bars were both increased.—B. C. W.

Mechanical and Physical Properties of Titanium-Stabilized Austenitic Cr–Ni Steels. Z. Eminger, A. Fiala, and J. Slajs.

(*Hutnické Listy*, 1954, **9**, (9), 514–523). [In Czech]. Results of researches on the effect of titanium additions to 18/8 Cr–Ni steels are reported, with special reference to inhibiting intercrystalline corrosion, and to the mechanical and magnetic properties. The state of the titanium in the metal and its reactions with carbon are considered. 'Inter-' but not 'intra-'crystalline corrosion is reduced by titanium additions, on the other hand, the additions make the steelmaking more complex.—P. F.

Thermal Checking of Wrought Steel Railway Wheel Material. H. R. Wetenkamp. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 649–654). The mechanism of formation of small cracks (thermal checks), that are formed as a result of two heat cycles is discussed. These cracks usually occur on the treads of railway wagon wheels. The reasons for the cracks forming more readily in the higher plain carbon steels are discussed. The contraction of martensite on tempering appears to be the cause.—D. H.

1·5 Per Cent Carbon Cast-Steel Railroad Car Wheels. N. A. Matthews and R. A. Flinn. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, May, 617–621). A cast steel (1½% C) wheel is described for use in railway wagons. Dynamometers and service tests showed that the wheel overcame thermal checking arising from brake-shoe action. Ductility was achieved by a combination of close analysis control and a two-stage heat-treatment producing a pearlitic matrix with carbides favourably dispersed. The excess carbide promotes increased wear resistance at a given hardness level.—D. H.

METALLOGRAPHY

Metallographic Polishing of Cast Iron. A Simplified Method using Diamond Abrasives. L. E. Samuels. (*J. Iron Steel Inst.*, 1955, **180**, May, 23–25). [This issue].

Austenitic Grain Size Measurement of Steels—Improvement of the Oxidation Method of Determination. A. Kohn. (*Metal Treatment and Drop Forg.*, 1954, **21**, Aug., 359–364). This is an English version of the paper which appeared in *Rev. Mét.*, 1954, **51**, Feb., 129–137 (*see J. Iron Steel Inst.*, 1955, **179**, Jan., 99).

X-Ray Investigations of Graphite in Iron-Carbon Alloys. W. Gruhl and E. G. Nickel. (*Giesserei*, 1954, **41**, Sept. 2, 453–456). An investigation is described in which six graphites were examined using a Geiger counter goniometer. The graphites investigated had been separated chemically from cast irons and included kish graphite, lamella graphite, temper carbon, and different spheroidal graphites. They were compared with a naturally occurring Ceylon graphite. The kish graphite was found to be very similar to that from Ceylon. Relative intensities of the different diffraction lines are tabulated and the results interpreted in terms of lattice structure.—R. J. W.

Report of Committee E-4 on Metallography. (*Amer. Soc. Test. Mat. Preprint No.* 57, 1954). The structures of bainite and martensite after the same tempering treatments have been examined by electron microscopy. Photomicrographs are shown. Bainites produced by isothermal transformation at 500° and 700° F. and quenched martensite were examined as formed and after tempering at 800°, 1100°, and 1250° F.

Sigma Phase—a Review. A. J. Lena. (*Metal Progress*, 1954, **66**, Sept., 122–128). Methods of identifying the sigma phase in stainless steels are explained. These include X-ray and microscopic methods. Details of etching solution and techniques are given. The sigma phase has been found in binary and ternary alloys other than iron–chromium and iron–chromium–nickel. The theories of sigma phase formation and the chi phase are also considered.—B. G. B.

Experimental Crystallography. R. E. Rundle. (*Annual Rev. Phys. Chem.*, 1951, **2**, 235–254). This review is mainly devoted to structure determination by neutron diffraction and X-ray methods, and incorporates information available up to November, 1950. Neutron diffraction from paramagnetic, ferromagnetic, and antiferromagnetic materials, and recent structure determinations by neutron diffraction are outlined for thorium, zirconium and uranium hydrides, and thorium dicarbide. The application of modern computational developments and the increased proportion of three-dimensional X-ray structure analyses are noted. Among recent advances in structure determination certain unusual structures among oxides, sulphides, selenides, and tellurides are mentioned.—J. E. J.

Band Theory and Crystal Structure. R. Smoluchowski and J. S. Koehler. (*Annual Rev. Phys. Chem.*, 1951, **2**, 187–216). The Sommerfield free electron theory and the band theory, first developed by Bloch and Brillouin, are outlined. The relationship between electronic and crystal structure is discussed, and the application of the band theory to the better understanding of the properties and crystal structure of metals is considered. Pure metals and polymorphism, limits of solubility and the structure of alloy phases, and aluminium alloys are discussed. In general, both the band theory and atomic theory must be applied for the satisfactory understanding of crystalline properties.—J. E. J.

Nondestructive Test Gives Austenite, Martensite Percentages. S. Storchheim. (*Iron Age*, 1954, **174**, July 1, 108–111). The theory and details are given of a rapid test for determining the amounts of austenite and martensite in fine (0·0004 in. dia.) stainless steel wire. The method combines both a magnetic test and X-ray diffraction techniques.—D. L. C. P.

Kinetics of the Martensite Transformation in a Hyper-Eutectoid Steel. J. Philibert and C. Crussard. (*J. Iron Steel Inst.*, 1955, **180**, May, 39–48). [This issue].

A Magnetic Balance for Measuring the Magnetic Moment of Ferromagnetic Material. O. Hedebrant. (*Jernkontorets Ann.*, 1954, **138**, (10), 643–654). [In Swedish]. Details are given of this balance, used for studying transformation kinetics in alloys. It gives rapid and accurate results at room temperature, and can be adapted to function at other temperatures. Measurements are made using a field of 12,000 oersteds, thus giving independence from sample shape.

A Property of Binary Iron Alloys. T. G. O. Berg. (*J. Phys. Radium*, 1954, **15**, Feb., 99–100). [In French]. Systems formed between iron and elements of higher atomic number contain two phases, solid solution α of uniform electron density, and a phase α' where the *s* electrons of the added element interact preferentially with the electrons of the iron atoms and not with the *3d* electrons. The extent of the α domain is fixed by the free energy of the *3d* electrons, whilst that of the α' is Δx where $\Delta x(N-2) \leqslant 0{\cdot}2$ and N is the number of *s* electrons per atom of the added element. At higher concentrations an intermetallic compound precipitates.

Diffusion in Metallic Solid Solutions. U. Landergren. (*Jernkontorets Ann.*, 1954, **138**, (10), 619–642). [In Swedish]. Fick's diffusion laws are discussed with particular referenc to their limitations as applied to metallic interdiffusion. Details are given of the Kirkendall effect, together with Darken's phenomenological diffusion theory. Reasons are given for the probability that diffusion in face-centred-cubic metals take place through lattice vacancies. (65 references).

Manganese Modification of the Fe–S–O System. D. C. Hilty and W. Crafts. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Sept., Section 1, 959–967). The authors propose a qualitative pseudo-ternary solidification diagram for the Fe–S–O system modified by manganese, supported by experimental derivation of an isothermal section at 1475° C. and 1% Mn in the solid-metal phase. The solubility of oxygen in liquid iron containing 1% Mn has been determined at 1600° C. and found to increase as the sulphur content increases above 0·15%.—G. F.

Diffusion of Boron in Alpha Iron. P. E. Busby and C. Wells. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Sept., Section 1, 972). The authors discuss the available data on the diffusion and solubility of boron in the α and γ phases in iron and steel, and conclude that the diffusion ($D\alpha$) in α-iron may be represented by the equation $D\alpha = 10^6 e^{-62,060/RT}$. It is suggested that boron forms a substitutional solid solution in α-iron and an interstitial solid solution in γ-iron.—G. F.

Precipitation of Iron Oxide from Alpha Fe–O Solid Solutions. A. U. Seybolt. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Sept., Section 1, 979–982). By metallographic methods, the author has studied the precipitation of FeO from α-phase Fe–O solid solutions and shows that it is composed largely of barely resolvable spheroidal particles. No evidence has been found of grain-boundary oxide films. The results are compared with those predicted from the Fe–O phase diagram.—G. F.

The Mechanism of Diffusion in Interstitial Solid Solutions. H. Schumann. (*Met. u. Giesserei Techn.*, 1954, **4**, Sept., 385–388). It has been shown, by using the most accurate numerical values available for activating energies in the systems α-iron–hydrogen, γ-iron–hydrogen, α-iron–nitrogen, γ-iron–nitrogen, α-iron–carbon, and γ-iron–carbon, that the

activating energies of diffusion are by no means directly proportional to the normal valency radii of hydrogen, nitrogen, and carbon.—L. J. L.

CORROSION

Probolog—An Application of Eddy Current Techniques to Non-Destructive Testing. W. J. Warren. (*Corrosion*, 1954, **10**, Oct., 318–323). An instrument for detecting faults, *e.g.*, corrosion pits, in non-magnetic metals is described.—J. F. S.

Electrolytic Etch Cuts Corrosion Test Time. J. D. Roach and H. H. Hollenbeck. (*Iron Age*, 1954, **173**, June 24, 100–103). A new corrosion test for some stainless steels is reported for indicating the susceptibility to intergranular corrosion. It involves an electrolytic etch in 10% oxalic acid solution, before microscopically examining the specimen; the presence of chromium carbides can thus be deduced. The test can also be used to show whether stabilized grades are completely stabilized, but they cannot be tested for corrosion by the method, because of sigma formation.—D. L. C. P.

Low Carbon Stainless Resists Intergranular Corrosion. R. E. Paret. (*Iron Age*, 1954, **173**, May 6, 132–134). It is explained how chromium carbide formation during welding and stress relieving leads to intergranular corrosion in stainless steel exposed to severe conditions. In applications where the condition cannot be rectified by annealing, one remedy may be the use of low carbon stainless steel. Properties of four types with carbon 0·03 to 0·1% are given.—D. L. C. P.

Corrosion Control by Anodic Protection. C. Edeleanu. (*Metallurgia*, 1954, **50**, Sept., 113–116). The use of anodic protection (as opposed to the more usual cathodic protection) of metals is discussed. A pilot plant is described for testing the anodic protection of stainless steel in a boiler used for sulphuric acid solution. The results obtained are given and have been extremely satisfactory; the corrosion of the steel has been successfully prevented.—B. G. B.

Factors Affecting the Testing of Stainless Steels in Boiling Concentrated Nitric Acid. J. E. Truman. (*J. Appl. Chem.*, 1954, **25**, May, 273–283). Accumulation of the corrosion products tends to increase the rate of attack of boiling nitric acid on stainless steel, chiefly owing to the presence of sexivalent chromium. Frequent replacement of the acid is not necessarily sufficient as steels once attacked by sexivalent chromium have a different resistance to nitric acid. Test procedures must be suitably modified in order to avoid acceptance of steels which may be less corrosion resistant in service.—J. O. L.

The Action of Cl^- and NO_3^- Ions in the Anodic Corrosion of 18 : 8 Stainless Steel. M. Serra Ribera and S. Feliu Matas. (*Inst. Hierro Acero*, 1954, **7**, July-Sept., 349–356). [In Spanish]. The anodic corrosion of 18/8 stainless steel, water quenched from 1200° C., was studied in a variety of solutions. Polarization curves and metallographic examination indicated that chloride and nitrate ions develop a local marked depolarization; in fact, chloride ions can make the surface active. (18 references).—P. S.

Inhibitor Evaluation by the Pearson Null Bridge. B. L. Cross and N. Hackerman. (*Corrosion*, 1954, **10**, Nov., 407–412). A Pearson null bridge was used to evaluate eight compounds and three commercial inhibitors using steel in aqueous sodium sulphate as the corrosion system. The anode and cathode polarization and 'film resistance' curves were obtained for isopropylamine, isobutylamine, di-*n*-butylamine, thiourea, ethylene thiourea, potassium chromate and zinc sulphate are given. Fairly good correlation, on a qualitative basis only, was obtained with other studies of inhibitor mechanism.—J. F. S.

Corrosion of Refinery Equipment by Sulfuric Acid and Sulfuric Acid Sludges. V. J. Groth and R. J. Hafsten. (*Corrosion*, 1954, **10**, Nov., 368–390). The corrosion resistance and related properties of materials used for handling sulphuric acid solutions are considered. Numerous examples from petroleum refineries are quoted and results of laboratory tests are reported.—J. F. S.

Sulfide Corrosion Cracking of Oil Production Equipment. N.A.C.E. Technical Unit Committee 1-G. (*Corrosion*, 1954, **10**, Nov., 413–419). Field experience of the cracking of metals (mainly steels) when exposed to a tensile stress in a hydrogen sulphide environment as part of oil production equipment is presented and discussed. Some field tests are reported.—J. F. S.

Radiometric Study of the Adsorption Characteristics of a Calcium Sulfonate Rust Inhibitor. Van Hong, S. L. Eisler, D. Bootzin, and A. Harrison. (*Corrosion*, 1954, **10**, Oct., 343–348). Calcium dinonyl naphthalene sulphonate containing radiocalcium was applied, in oil solution, to sand-blasted steel. Adsorption measurements with an alpha-ray counter after various conditioning periods at different humidities indicated that adsorption increased slowly from 0 to 40% relative humidity, and then more rapidly to a maximum at 100%. This technique of studying rust inhibitors is recommended.

Pipe-Type Cable Corrosion Protection Practices in the Utilities Industry. N. A. C. E. Technical Unit Committee T-4B. (*Corrosion*, 1954, **10**, Sept., 299–313). This First Interim Report of N.A.C.E. Technical Unit Committee T-4B on Corrosion of Cable Sheaths classifies replies to a questionnaire on field practices in the protection of oil and gas-filled steel tubes carrying high-voltage cables.—R. A. R.

ANALYSIS

X-Ray Fluorescence Cuts Metal Analysis Time. J. R Mihalisin. (*Iron Age*, 1954, **174**, July 15, 108–110). A time-saving method of determining iron, chromium, and cobalt in alloys high in chromium and cobalt is described. It involves the combined use of X-ray fluorescence and established analysis methods.

The Versatility of the Direct Reading Spectrometer. L. W. McNeil and A. F. Ernster. (*Blast Furn. Steel Plant*, 1954, **42**, Oct., 1184–1187). The use of a Baird direct reading spectrometer by the Ford Motor Company is described. The standard deviation obtained from repeated runs on samples of low-alloy steel, stainless, and high-alloy tool steels, cobalt-base and nickel-base alloys are given and discussed. Alterations made to the setting of the instrument for certain alloys are explained.—B. G. B.

The Semi-Microanalysis of Carbon in Steels. P. Flamont and J. Marot. (*Rev. Mét.*, 1954, **51**, Oct., 702–708). In the apparatus described the SO_2 and SO_3 evolved during combustion of the steel sample are absorbed by an acid bichromate solution, and water vapour and CO_2 are trapped by freezing at − 180° C. The CO_2 is then liberated under vacuum at 60° C. Carbon contents from 0·01 to 0·09% may be determined on samples as small as 20 mg.—A. G.

Manganese Determination in Iron and Steel. H. Lilie and C. Rudat. (*Met. u. Giesserei Techn.*, 1954, **4**, Sept., 409). The Procter-Smith process is used in the chemical laboratories of the East German steel industry for determining manganese contents not exceeding 1·5% and the National Bureau of Standard's persulphate/silver-nitrate method for manganese in the 1·5–10% range. By adding sodium nitrite to the arsenious acid the end point of the titration is clearly seen.

Determination of High Aluminium Contents in Cast Irons without the Use of the Mercury Cathode. B. Bieber and Z. Večeřa. (*Slévárenství*, 1954, **2**, (7), 206–210). [In Czech]. Aluminium contents of 1 to 25% are determined by first removing silica and graphite from a solution of the sample in sulphuric acid, precipitating part of the iron with sodium bicarbonate in the presence of some hydrazine sulphate, and the remaining iron by alpha-nitroso beta-naphtol. Aluminium is determined as alumina, precipitated from the filtrate with ammonia. The method is modified in the presence of chromium, but can be employed if the molar Cr/Al ratio does not exceed unity.—P. F.

Determination of McQuaid–Ehn Grain Size by Spectrochemical Analysis of Ladle Samples. G. E. Ressler. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 300–302). At the Timken Roller Bearing Co., the aluminium content of steels is determined spectrochemically from pin samples taken from the ladle, as an aid to establishing the austenitic grain-size rating. The author outlines the practice, presents results, and indicates the advantages of spectrochemical analysis over the normal chemical methods.—G. F.

Melting Control of Electric Furnace Steel with a Direct-Reading Spectrometer. G. C. Delplace. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 77–79). A direct-reading spectrometer is in use at the Rotary Electric Steel Co. for analytical control. It is calibrated for the nine elements: Manganese, silicon, chromium, nickel, molybdenum, copper, aluminium, tin, and lead. The analytical procedure and accuracy are indicated.—G. F.

Validity of Results of Rapid Methods of Analysis for High-alloy Steels. M. L. Windle and W. H. Magrun. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1953, **11**, 87–90).

The authors make a statistical study of the results of rapid analytical methods, and show that 30 or more comparative analyses will supply sufficient data to determine the maximum deviation to be expected for the particular method considered.—G. F.

The Spectrographic Analysis of Magnesium in Nodular Cast Irons. A. Rodriguez Perez and F. Burriel Marti. (*Inst. Hierro Acero*, 1954, **7**, July-Sept., 345–348). [In Spanish]. A simple and rapid method for the determination of magnesium in nodular cast irons is described. Working curves for the line pairs Mg-2802·7/Fe-2813·29 and Mg-2795·54/Fe-2788·11 were made from chemically prepared standards and applied to the spectrographic analysis of six samples. Comparison with two methods of wet analysis showed that the former were more consistent.—P. S.

Spectrographic Determination of Elements in High Concentrations by the Method of Transference to the Counter-Electrode. F. Malamand. (*Rep. 16ème Congr. Group. Avancement Méthodes Anal. Spectrogr. Produits Metallurg.*, **1953**, 109–125). [In French]. Further details are given of a previously published method, the principle of which is that the constituents of the alloy are deposited in a preliminary excitation on to a suitable counter-electrode, which is in turn made the specimen. Many lines of complex spectra are suppressed, and increased precision is obtained. Relative errors of about 0·5% are obtained.—L. D. H.

Study of the Effect of Carbon in the Spectrographic Analysis of Refractory Materials. R. Ricard. (*Rep. 16ème Congr. Group. Avancement Méthodes Anal. Spectrogr. Produits Metallurg.*, **1953**, 165–169). [In French]. The effect of mixing carbon powder with the materials to be analysed is studied. Admixture of three parts of carbon to one of the substance is often advantageous, in both qualitative and quantitative work. The thermal and electrical conductivities of the sample are improved, and oxides are reduced to the more volatile metals.—L. D. H.

The Absorptiometric Determination of Silicon in Ferrous Materials. (*Metallurgia*, 1954, **50**, Sept., 145–148). An absorptiometric method of determining silicon in all types of plain carbon and alloy steels and cast irons has been developed which meets the requirements of routine work. There is no loss in accuracy and the time required is much less than that for reduction with stannous chloride.—B. G. B.

Sampling of Pig Iron for the Estimation of Carbon. (*Bradley's Magazine*, 1954, Sept., 3–4). An investigation of methods of sampling high-carbon iron for the estimation of carbon was recently made by the Methods of Analysis Committee of B.I.S.R.A. The conclusions drawn and recommendations made are reviewed. Solid samples suffer least from the loss of graphite during sampling and consistent carbon analyses can be obtained. Discrepancies may occur even with solid samples of hematite pig iron due to the very coarse graphite flakes and segregated structure.—L. E. W.

Determination of Sulphur in Magnetite and Apatite Using a Lindberg H.F. Induction Furnace. U. Fernlund and S. Zechner. (*Jernkontorets Ann.*, 1954, **138**, (10), 665–667). [In Swedish]. In this method the ore is heated under oxygen in an induction furnace, the SO_2 evolved being directly determined by titration with potassium iodate. The accelerator used consisted of a mixture of 7 parts by weight of tin filings and 1 part Cr_2O_3. Fifty sulphur determinations per day can be made with a reproducibility of ± ·001%.—G. G. K.

HISTORICAL

A Short History of Iron and Steel Making in Finland. N. Hellén. (*J. Iron Steel Inst.*, 1955, **180**, May, 18–19). [This issue].

The Scientific Work of Eugen Piwowarski. H. Schiffers and W. Patterson. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, July, (13), 610–624). The work of Eugen Piwowarsky is reviewed. His seven books, 216 publications, and 37 patents are listed.—R. J. W.

The End of the Neolithic Period and the Appearance of Metals. A. A. Sanfourche. (*Rev. Mét.*, 1954, **51**, Aug., 517–523). Because of corrosion the examples of metallic objects before the end of the neolithic period are few. It is probable that the dawn of the metal age was earlier than is generally admitted.—A. G.

French Pioneer of Metallography: Floris Osmond. E. N. Simons. (*Brit. Steelmaker*, 1954, **20**, Nov., 426–427, 435). A brief account is given of the life of Floris Osmond and of his contribution as a pioneer of the metallographic examination of the structure of metals.—G. F.

ECONOMICS AND STATISTICS

Our Industry—Decline and Recovery 1910–1933. Sir Charles Bruce-Gardner. (*J. Iron Steel Inst.*, 1955, **180**, May, 1–12). [This issue].

European Steel Problems in 1954. M. J. Layton. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1397–1402). The author considers the demand and supply position for the European steel industry and the various estimates that have been made in order to provide as sound a basis as possible for future investment plans.—J. P.

ESC, an Industry Grows. (*ESC. News*, 1954, **8**, (1), 3–7). An historical survey is made of the part played by the English Steel Corp. and its predecessors in the economic development of Great Britain.—A. G.

Plan for the Modernization of the Iron and Steel Industry and Iron Ore Mines. (1954-1957). (*Usine Nouvelle*, 1954, **10**, Sept. 9, 65–67; Sept. 16, 21–25; Sept. 23, 23–25; Sept. 30, 21). All aspects of the development of the French industry during the next three years are considered. The national and international markets in 1957 are estimated for pig iron, ordinary steel in its various finished forms, and special steels.—T. E. D.

The French Iron and Steel Industry. (*Metal Bull.*, 1954, Nov., Special Issue, 9–30). A comprehensive account of the French iron and steel industry is given with details of outputs of pig iron and steel and a description of the progress in the modernization and expansion of the industry.—B. G. B.

The Rôle of Southern Rhodesia's Steel Industry in Rhodesian Mining. (*Min. J.*, 1954, **243**, Aug. 6, 155–157). The production of iron ore, limestone, and coal for use at the Que Que iron and steel works, opened in 1948, is described.—B. G. B.

MISCELLANEOUS

The Planning and Preparation of Work in American Iron and Steel Works. R. Hillingmeier. (*Stahl u. Eisen*, 1954, **74**, Oct. 21, 1413–1417). The methods used at some large steelworks in the U.S.A. for planning and preparing production schedules are surveyed and their possible application to German works is discussed.—J. P.

Traffic Congestion in Iron and Steel Works: Causes and Remedies. M. D. J. Brisby. (*Iron Coal Trades Rev.*, 1954, **169**, Nov. 5, 1103–1109). The fundamental cause of steelworks traffic congestion is the inequality of the rates at which commodities arrive and at which they can be dealt with. The author suggests standards for siding capacity, speed of wagon discharge, and locomotive availability. The importance of planning and communications (using very high frequency radio) is considered.—G. F.

Central Oxygen and Acetylene Plants in Large Works. H. Groot-Roessink. (*Lastechniek*, 1954, **20**, Sept., 153–157). [In Dutch]. This article discusses from a practical point of view the installation of oxygen and acetylene plants in the works. An installation is described and illustrated.—R. S.

Oxygen for Steelworks Use; Assessment of Economic Supply. H. G. Jones, A. M. Lee, and D. T. Steer. (*Iron Coal Trades Rev.*, 1954, **169**, Sept. 10, 613–617). The authors have estimated the future requirements of oxygen by the Steel Division of the Steel Company of Wales Ltd., for use in the O.H. furnaces, machine-scarfing of slabs, and general purposes. From this they deduce the most economical method of meeting this demand.—G. F.

Problems Relating to Dust and the Removal of Dust from Smoke. R. Nagel. (*BWK.*, 1954, **6**, Sept., 344–348). The modes of operation of electrostatic and cyclone dust filters are discussed and compared.—P. F.

Controlled Air Conditioning in Metal Finishing. (*Indust. Finishing*, 1954, **7**, Aug., 31–36). Air conditioning is essential in such work as the quality production of precision mechanisms. The principles of air cleaning, humidity control, and air heating systems are outlined.—K. E. J.

Air Pollution Control in the Bethlehem Steel Company. A. D. Brandt. (*Iron Steel Eng.*, 1954, **31**, Aug., 103–106). Practices adopted at Bethlehem Steel Co. in the coke-oven, blast-furnace and sinter plants, and open-hearth and electric furnaces and Bessemer plants to prevent the discharge to atmosphere of objectionable impurities are described.

NEW PUBLICATIONS

BOOK NOTICES

KNUDSEN, JAMES G., and DONALD L. KATZ. "*Fluid Dynamics and Heat Transfer.*" (University of Michigan Engineering Research Institute Bulletin No. 37.) 8vo, pp. ix + 243. Illustrated. Michigan, 1954: Engineering Research Institute, University of Michigan. (Price 36*s.*)

The authors investigate how far our knowledge of fluid flow in and around various systems can explain the empirical observations of forced convection heat transfer in these systems.

The first part of the book thus deals with the velocity distribution observed in laminar and turbulent flow in smooth and rough tubes, annular spaces, immersed bodies, and the more practical cases for furnace designers of banks of tubes and baffled heat exchangers. The treatment of the various cases is not equally detailed, because in fact research has not proceeded to anything like the same extent with the more complicated systems of banks of tubes as with simpler shapes. Thus, in the case of tube banks, the treatment of flow is purely qualitative.

The second part of the book deals with the transfer of momentum from the fluid to the walls, which appears as friction for internal flow systems and as drag coefficients for external flow systems. The same geometrical systems are considered as in the first part, and here it is possible to give numerical formulæ for tube banks.

The third part of the book applies these results to measurements of convection heat transfer in the same systems.

The authors stress the usefulness of the concept of the laminar layer through which heat transfer must take place by conduction, although they confess there is no direct evidence for the existence of this layer. They also point out clearly that there can be useless and useful turbulence. This discrimination is not carried to the point where the engineer can use it to calculate the most economical pressure drop for a heat exchanger. Generally speaking the book is of more interest to a physicist seeking a clear statement of the results of the heat and momentum transfer analogy than to an engineer who wishes to design the most economical plant, and to the former the book is strongly recommended.

M. W. THRING.

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Wrought Steel Wheels.*" (Steel Products Manual.) Revised February 1955. La. 4to, pp. 61. Illustrated. New York, 1955: The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures.*" Presented at the Fifty-Seventh Annual Meeting, American Society for Testing Materials, Chicago, Ill., June 17, 1954. (ASTM Special Technical Publication No. 165). 8vo, pp. [v +] 175. Illustrated. Philadelphia, Pa., 1954: The Society. (Price $3)

BARNARD, G. P. "*Modern Mass Spectroscopy.*" With a Foreword by E. C. Bullard. (Physics in Industry.) La. 8vo, pp. 326. Illustrated. London, 1953: The Institute of Physics. (Price 50*s.*)

BRITISH IRON AND STEEL FEDERATION. "*Statistics of the Iron and Steel Industry of the United Kingdom for* 1953." La. 4to, pp. vii + 143. Illustrated. London [1954]: The Federation. (Price 7*s.* 6*d.*)

BRITISH IRON AND STEEL RESEARCH ASSOCIATION. "*The Prevention of Corrosion.*" 8vo, pp. 20. Illustrated. London, 1954: The Association. (Price 2*s.*)

BRITISH PRODUCTIVITY COUNCIL. "*Production Control.*" Report of a visit to the U.S.A. in 1951 of a Specialist Team on Production Planning and Control. La. 4to, pp. x + 130. Illustrated. London, 1953: The Council. (Price 5*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 970: 1955. "*Wrought Steels.*" In the Form of Bars, Billets and Forgings up to 6 in. Ruling Section for Automobile and General Engineering Purposes. (En Series.) 8vo, pp. 225. Illustrated. London, 1955: The Institution. (Price 12*s.* 6*d.*)

CAZAUD, R. "*Le Frottement et l'Usure des Métaux. Les Anti-Frictions.*" Préface de J. Cournot. La. 8vo, pp. xii + 221. Illustrated. Paris, 1955: Dunod. (Price 2,250 fr.)

CONTRACTOR, G. P. "*Some Aspects of the Canadian Iron and Steel Industry with Particular Reference to British Columbia.*" (British Columbia Research Council Technical Bulletin No. 21.) La. 4to, pp. ii + 180. Illustrated. Vancouver, B.C., 1954: British Columbia Research Council at the University of British Columbia. (Price $4)

FREUDENTHALER, JOSEF. "*Eisen auf immerdar.*" Geschichte der Stadt und des Bezirkes Leoben in Kulturbildern. 3. durchges. u. erg. Aufl. 8vo, pp. 420. Illustrated. Leoben, 1954: The Author. (Price 120 schillings)

HILBERT, HEINRICH L. "*Stanzereitechnik.*" Bd. I. "*Schneidende Werkzeuge, Arbeitspläne, Entwurf und Herstellung der Werkzeuge, Maschinen zum Schneiden und Kalkulationen von Werkzeugen.*" 5. völlig überarb. Aufl. 8vo, pp. 349. Illustrated. München, 1954: Hanser Verlag. (Price DM 19.80)

HOARE, W. E. "*Some Recent Advances in Tinplate Manufacturing Processes.*" An address given at the Congresso Imballaggi, Parma, Italy, September, 1954. 8vo, pp. 27. Illustrated. London, 1955: Tin Research Institute.

HULL, J. L., and I. CORNET. "*Plastic Deformation of Metals. Survey of Literature* 1952–1953, *Inclusive.*" Prepared for the Sub-Committee on Plastic Flow, General Research Committee, American Iron and Steel Institute, T. F. Olt, Chairman. Contributions to the Metallurgy of Steel, No. 46. La. 4to, pp. v + 391 (mimeographed). New York, 1954: American Iron and Steel Institute.

IRON AND STEEL INSTITUTE. "*Third Report of the Ingot Moulds Sub-Committee.*" Submitted by The British Iron and Steel Research Association, Steel Making Division, Report SM/BA/48/53. (Iron and Steel Institute Special Report No. 52.) 8vo, pp. 72. Illustrated. London, 1955: The Institute. (Price 25*s.*; members 15*s.*)

"*Kempe's Engineers Year Book for* 1955." Edited by C. E. Prockter under the direction of B. W. Pendred, editor-in-chief of "The Engineer." 60th edition. 2 vols., 8vo, illustrated. Volume I, pp. 1345; Volume II, pp. 1413. London, 1955: Morgan Brothers (Publishers), Ltd. (Price 75*s.*, two volumes)

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His Royal Highness The Duke of Edinburgh, K.G.

The Joint Metallurgical Societies Meeting in Europe

Message from

His Royal Highness The Duke of Edinburgh, K.G.

Patron in the United Kingdom

Buckingham Palace

I extend a cordial greeting and warm welcome to all the delegates to the British Section of the international Metallurgical Conference assembled in London.

This Conference is another important example of co-operation between the British Commonwealth and the free peoples of the world in a field of research which has already during the present century exerted a profound influence on our material civilisation. The extension of knowledge of the physical properties of materials under varying conditions of stress and temperature is the basis of the new industrial revolution now in progress. Man's success in achieving supersonic speeds in flight, high pressure at high temperatures for economic power generation and the progressive control of atomic energy for industrial service are all dependent on this knowledge.

These applications have clearly demonstrated the limitations of our present knowledge. Therefore, I hope that this conference will provide a permanent form of organisation that will keep in constant review the progress of metallurgical research in all countries and promote its rapid application for the benefit of mankind.

I wish the Conference every success and I am confident that your continued association in work of such importance will foster and maintain understanding and goodwill between the various countries taking part.

Letter from

The Iron and Steel Institute and The Institute of Metals

to

His Royal Highness The Duke of Edinburgh, K.G.

Sir,

We have been deputed by the Councils of The Iron and Steel Institute and The Institute of Metals to thank Your Royal Highness most sincerely for consenting to be Patron in the United Kingdom of the forthcoming Joint Metallurgical Societies Meeting in Europe.

At this Meeting the American Institute of Mining and Metallurgical Engineers and the American Society for Metals are joining with some of the leading metallurgical Institutions in Great Britain, Germany, Belgium, France and Sweden to discuss matters of common interest bearing on the scientific and technical progress of the iron and steel and non-ferrous metals industries.

We believe that this is the first time that Members of these two influential American Institutions have accepted invitations to travel to Europe for a meeting of this kind. In addition, we expect representatives from many other countries, including countries of the Commonwealth —especially Canada, Australia, South Africa, India and Pakistan.

The Iron and Steel Institute and The Institute of Metals are responsible for organising the first section of the Meeting. The Opening Plenary Session will be in London on Wednesday, 1st June, 1955. During the following week, opportunities will be provided for visits to works and laboratories in various parts of England and Wales and in Scotland.

It is a great encouragement to all taking part in this Meeting, and especially to the Members of the Institutes whom we represent, that Your Royal Highness has shown your interest and approval by graciously consenting to be Patron.

On behalf of all Members of the Meeting we send Loyal Greetings to Your Royal Highness.

We have the honour to be, Sir, Your Royal Highness's humble and obedient servants,

On behalf of
The Iron and Steel Institute

R G Lyttelton

President

President-Elect

Kenneth Headlam-Morley

Secretary

On behalf of
The Institute of Metals

S. F. Dorey

President

President-Elect

Secretary

29th March, 1955